CHAPTER 3

CONSTRUCTION OF AN INTERNAL COMBUSTION ENGINE

LEARNING OBJECTIVE: *Identify the stationary and moving parts, the operating principles and their functions, and the basic testing procedures used in constructing an internal combustion engine. Describe the techniques used in reconditioning and adjusting valves and timing gear installation.*

In the preceding chapter, you learned how the internal combustion engine operates. You also learned how the basic moving parts of an engine move in a timed relationship to one another during engine operation.

This chapter provides information on the many stationary and moving parts of an internal combustion engine. As a CM, you should be concerned with how these parts are made, what materials they are made of, and their relationship to one another for smooth and efficient operation of an internal combustion engine.

The information provided is to help you diagnose malfunctions of an engine and ways to correct them. Since the gasoline and diesel engines used in construction equipment of today are basically the same internally, the majority of information provided applies to both.

ENGINE CONSTRUCTION

LEARNING OBJECTIVE: *Recognize operating principles and functions of stationary and moving parts within an internal* combustion engine. *Describe techniques used in valve reconditioning and timing gear installation.*

Basic engine construction varies little, regardless of size and design of the engine. The intended use of an engine must be considered before the design and size can be determined.The temperature at which an engine operates determines what metals must be used in its construction.

To simplify the service parts and to simplify process and servicing procedures in the field, the present-day trend in engine construction and design is toward **ENGINE FAMILIES.** Typically, there are several types of engines because of the many jobs to be done; however, the service and service parts problem can be simplified by designing engines so they are closely related in cylinder size, valve arrangement, and so forth. For example, the GM series 71 engines can be obtained in two-, three-, four-, and six-cylinder in-line models. GM V-type engines come in 6-, 8-, 12-, and 16-cylinder models. These engines are designed in such a way that many of the internal parts can be used on any of the models.

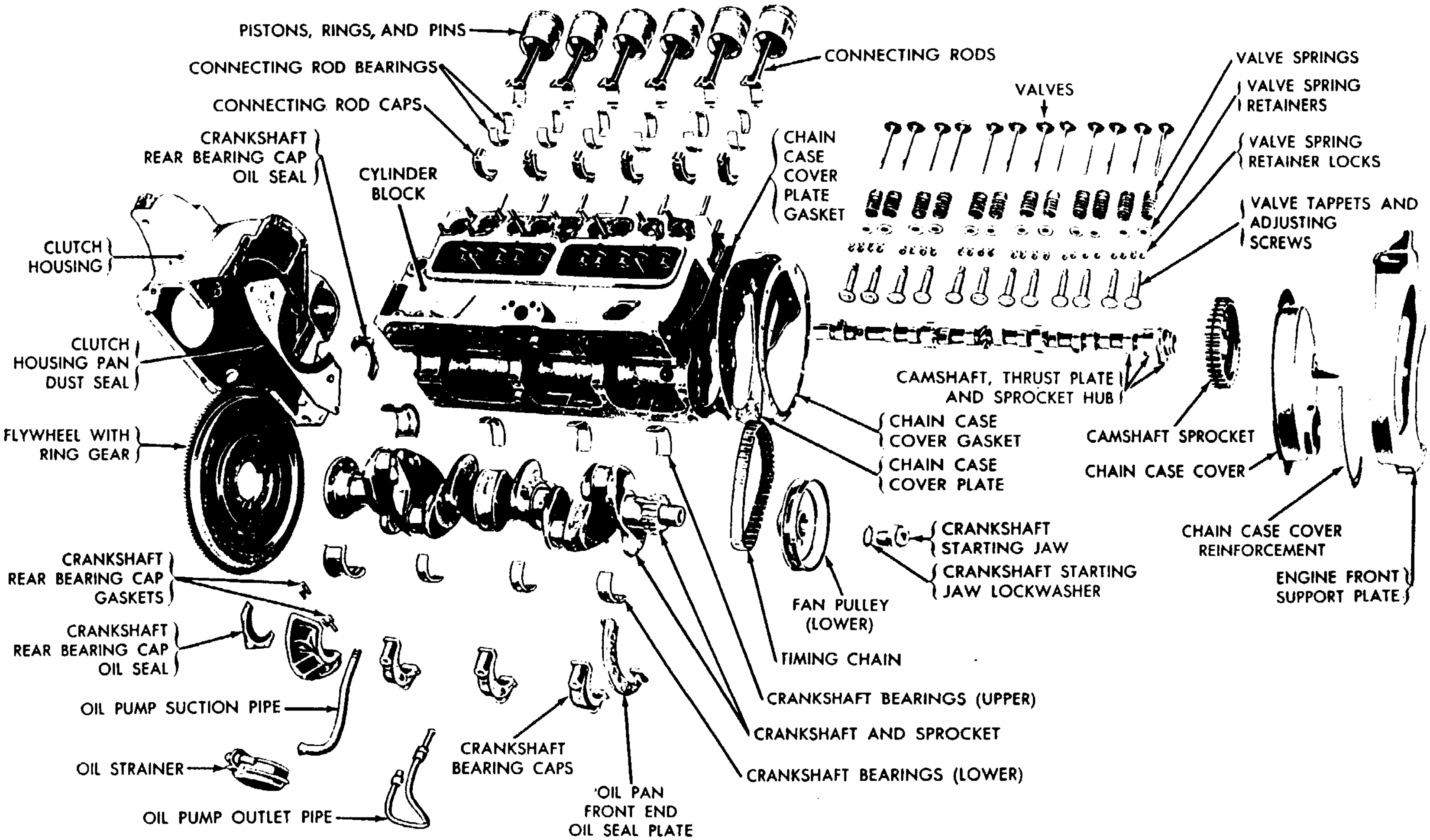
STATIONARY PARTS OF AN ENGINE

The stationary parts of an engine include the cylinder block and cylinders, the cylinder head or heads, and the exhaust and intake manifolds. These parts furnish the framework of the engine. All movable parts are attached to or fitted into this framework.

Engine Cylinder Block

The cylinder block is the basic frame of a liquid-cooled engine whether it be in-line, horizontally opposed, or V-type. The cylinder block (fig. 3-1) is a solid casting made of cast iron or aluminum that contains the crankcase, the cylinders, the coolant passages, the lubricating passages, and, in the case of flathead engines, the valves seats. the ports, and the guides.

The cylinder block is a one-piece casting usually made of an iron alloy that contains nickel and molybdenum. This is the best overall material for cylinder blocks. It provides excellent wearing qualities, low material and production cost, and it only changes dimensions minimally when heated. Another material that is used for cylinder blocks, although not extensively, is aluminum. Aluminum is used whenever weight is a consideration. It is not practical to use for the following reasons:



FFigure 3-1.—Cylinder block and components.

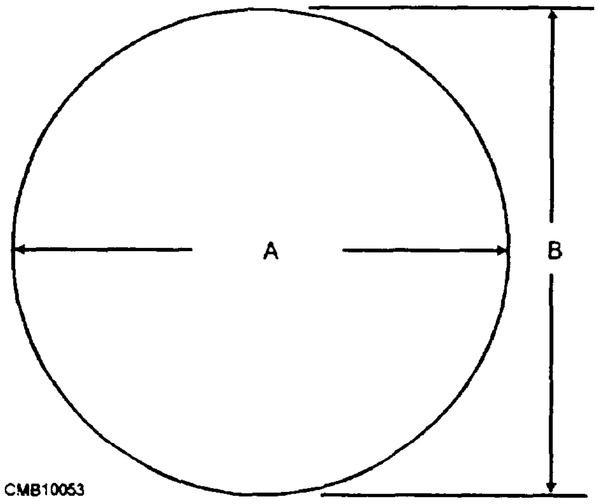
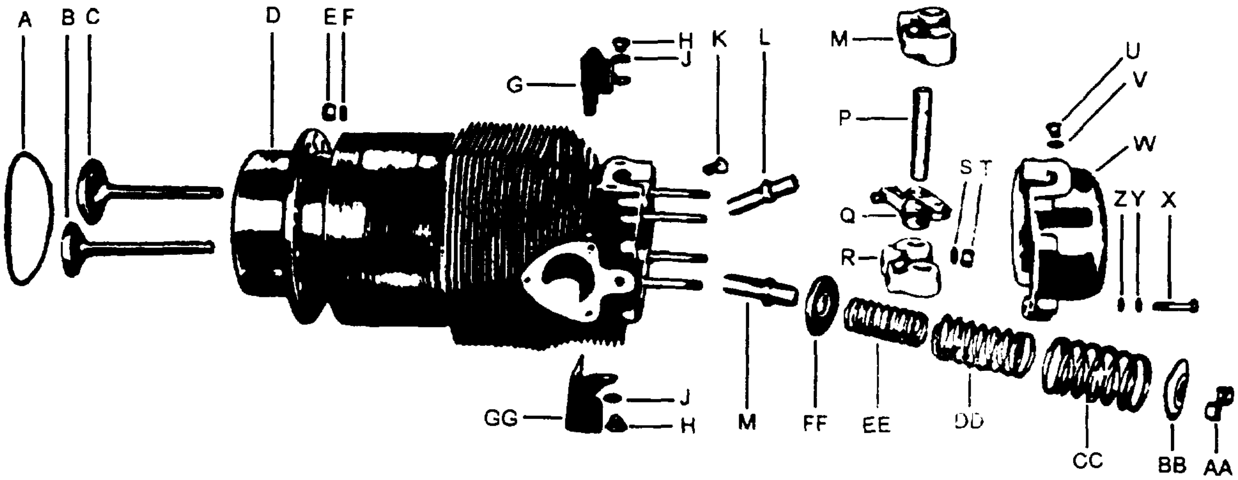


Figure 3-2.—Requirements of a cylinder.

- Aluminum is more expensive than cast iron.
- Aluminum is not as strong as cast iron.
- Because of its softness, it cannot be used on any surface of the block that is subject to wear. This necessitates the pressing, or casting, of steel sleeves into the cylinder bores. Threaded holes must be deeper. This introduces extra design considerations and increases production costs.
- Aluminum has a much higher expansion rate than iron when heated. This creates problems with maintaining tolerances.

The **CYLINDERS** are bored right into the block. A good cylinder must be round, not varying in diameter by more than approximately 0.0005 inch (0.012 mm) (fig. 3-2). The diameter of the cylinder must be uniform throughout its entire length. During normal engine operation, cylinder walls wear out-of-round, or they may become cracked and scored if not lubricated or cooled properly. The cylinders on an **AIR-COOLED** engine (fig. 3-3) are separate from the crankcase. They are made of forged steel. This material is most suitable for cylinders because of its excellent wearing qualities and its ability to withstand high temperatures that air-cooled cylinders obtain. The cylinders have rows of deep fins cast into them to dissipate engine heat. The cylinders are commonly mounted by securing the cylinder head to the crankcase with long studs and sandwiching the cylinders between the two. Another way of mounting the cylinders is to bolt them to the crankcase, and then secure the heads to the cylinders.



A– O-RING GASKET
B– EXHAUST VALVE
C– INTAKE VALVE
D– CYLINDER
E– CYLINDER BARREL NUT
F– LOCK NUT
G– DOME FIN DEFLECTOR (LH)
H– BOLT
J– LOCK WASHER
K– PRIMER NOZZLE ASSEMBLY
L– INTAKE VALVE GUIDE
M– EXHAUST VALVE GUIDE
N– CAMSHAFT BEARING CAP
P– ROCKER SHAFT
Q– ROCKER
R– ROCKER SUPPORT BRACKET
S– WASHER
T– SLOTTED NUT
U– ROCKER BOX COVER PLATE
V– TAB WASHER
W– VALVE ROCKER COVER
X– BOLT
Y– LOCK WASHER
Z– WASHER
AA– VALVE LOCK
BB– VALVE SPRING RETAINER
CC– OUTER VALVE SPRING
DD– INTERMEDIATE VALVE SPRING
EE– INNER VALVE SPRING
FF– VALVE RING SEAT
GG– DOME FIN DEFLECTOR (RH)

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Figure 3-3.—Air-cooled cylinder.

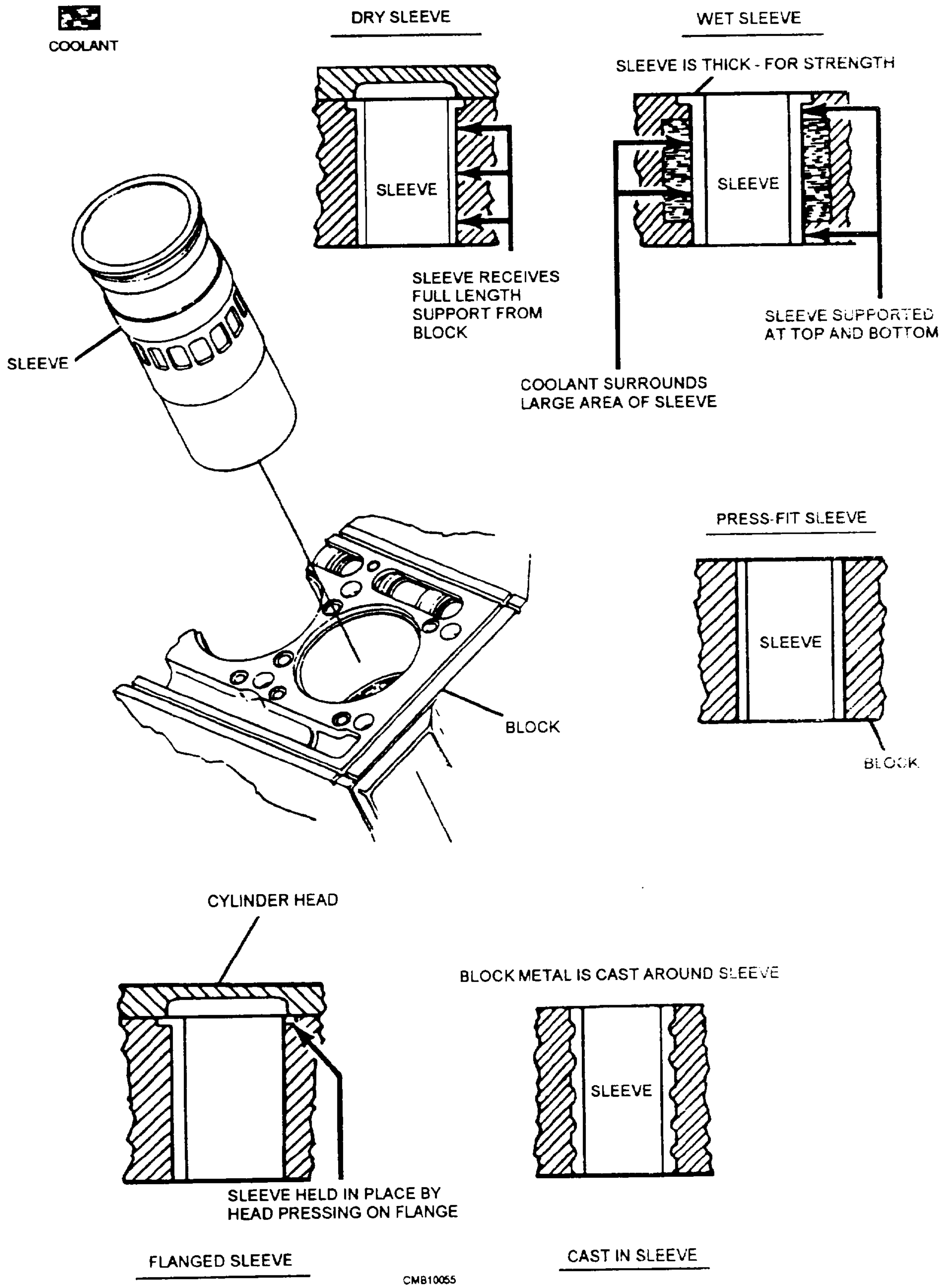


Figure 3-4.—Cylinder sleeves.

In liquid-cooled engines **CYLINDER SLEEVES** or **LINERS** (fig. 3-4) are used to provide a wearing surface, other than the cylinder block, for the pistons to ride against. This is important for the following reasons:

- Alloys of steel can be used that wears longer than the surfaces of the cylinder block. This increases engine life while keeping production costs down.
- Because the cylinders wear more than any other area of the block, the life of the block can be greatly extended by using sleeves. When overhaul time comes, the block can be renewed by just replacing the sleeves.
- Using a sleeve allows an engine to be made of other materials, such as aluminum, by providing the wearing qualities necessary for cylinders that aluminum cannot.

There are two types of cylinder sleeves: the **DRY-TYPE** and the **WET-TYPE.** A dry-type sleeve does not contact the coolant. The dry-type sleeve is pressed into a full cylinder that completely covers the water jacket. Because the sleeve has the block to support it, it can be very thin. The wet-type sleeve comes in direct contact with the coolant. It is also press-fitted into the cylinder. The difference is that the water jacket is open in the block and is completed by the sleeve. Because it gets no central support from the block, it is made thicker than a dry sleeve. Also because the sleeve completes the water jacket, it must fit so it seals in the coolant. This is accomplished by using a metallic sealing ring at the top and a rubber sealing ring at the bottom. There are three basic ways of securing the sleeves in the cylinder block as follows:

- Press in a sleeve that is tight enough to be held by friction.
- Provide a flange at the top of the block that locks the sleeve into place when the cylinder head is bolted into place. This is more desirable than a friction fit, because it locks the sleeve tightly.
- Cast the sleeve into the cylinder wall. This is a popular means of securing a sleeve in an aluminum block.

Whatever method is used to secure the sleeves, it is very important for the sleeve to fit tightly. This is so the sleeve can transfer heat effectively to the water jackets.

Most cylinder sleeve casualties are directly related to a lack of maintenance or improper operating procedures. Figure 3-5 shows two common types of cylinder sleeve casualties: cracks and scoring. Both types of casualties require replacement of the sleeve.

The cylinder block also provides the foundation for the cooling and lubricating systems. The cylinders of a liquid-cooled engine are surrounded by interconnecting passages cast in the block. Collectively, these passages form the **WATER JACKET** that allows the circulation of coolant through the cylinder block and the cylinder head to carry off excessive heat created by combustion. The water jacket is accessible through holes machined in the head and block to allow removal of the material used for casting of the cylinder block. These holes are called core holes and are sealed by **CORE HOLE PLUGS** (freeze plugs). These plugs are of two types: cup and disk. Figure 3-6 shows a typical installation of these plugs.

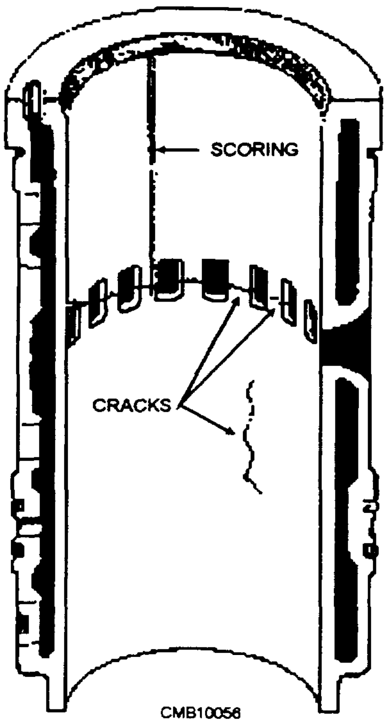


Figure 3-5.—Cylinder sleeve casualties.

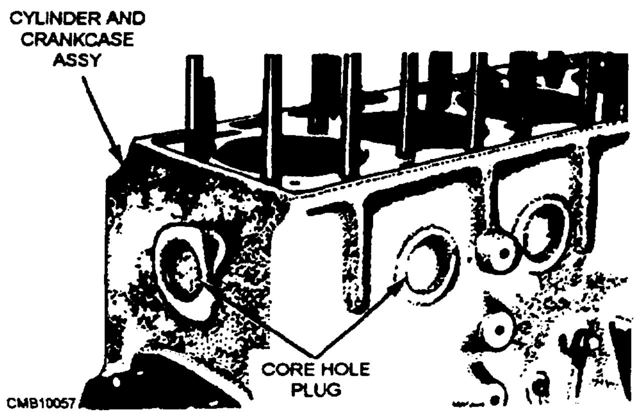


Figure 3-6.—Core hole plugs installed in cylinder block.

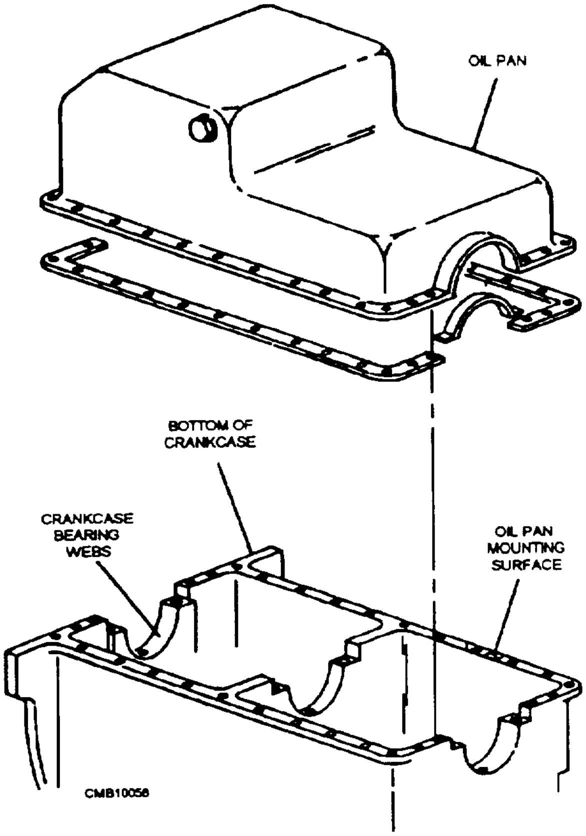


Figure 3-7.—Engine crankcase.

The **CRANKCASE** (fig. 3-7) is that part of the cylinder block below the cylinders. It supports and encloses the crankshaft and provides a reservoir for lubricating oil. The lower part of the crankcase is the **OIL PAN,** which is bolted at the bottom. The oil pan is made of cast aluminum or pressed steel and holds the lubricating oil for the engine. Since the oil pan is the lowest part of the engine, it must be strong enough to withstand blows from flying stones and obstructions sticking up from the road surface.

The crankcase also has mounting brackets to support the entire engine on the vehicle frame. These brackets are either an integral part of the crankcase or are bolted to it in such a way that they support the engine at three or four points. These points are cushioned by rubber mounts that insulate the frame and body of the vehicle from engine vibration. This prevents damage to engine supports and the transmission.

The crankcase (fig. 3-8) is the basic foundation of all air-cooled engines. It is made as a one- or two-piece casting that supports the crankshaft, provides the mounting surface for the cylinders and the oil pump, and has the lubrication passages cast into it. It is made

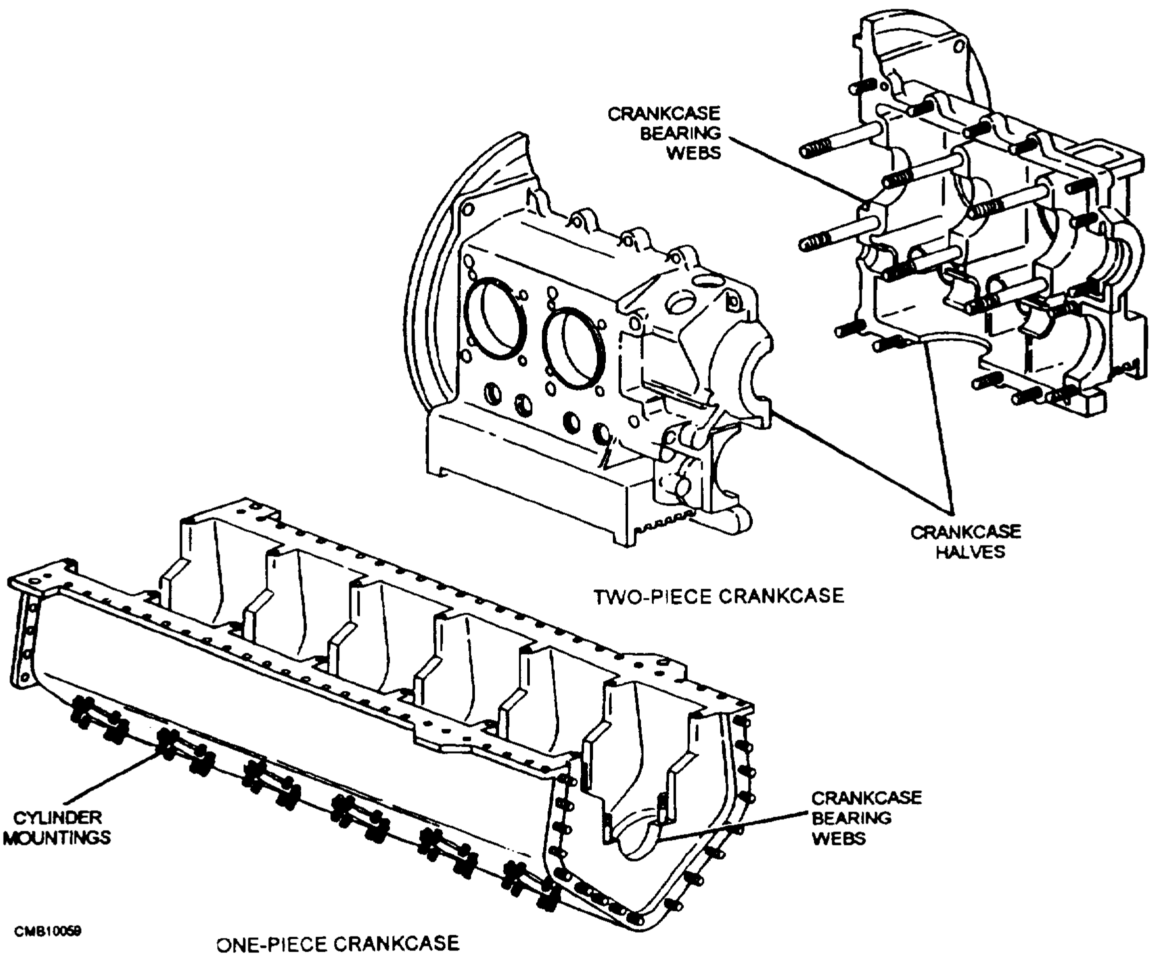


Figure 3-8.—Aircooled crankcase.

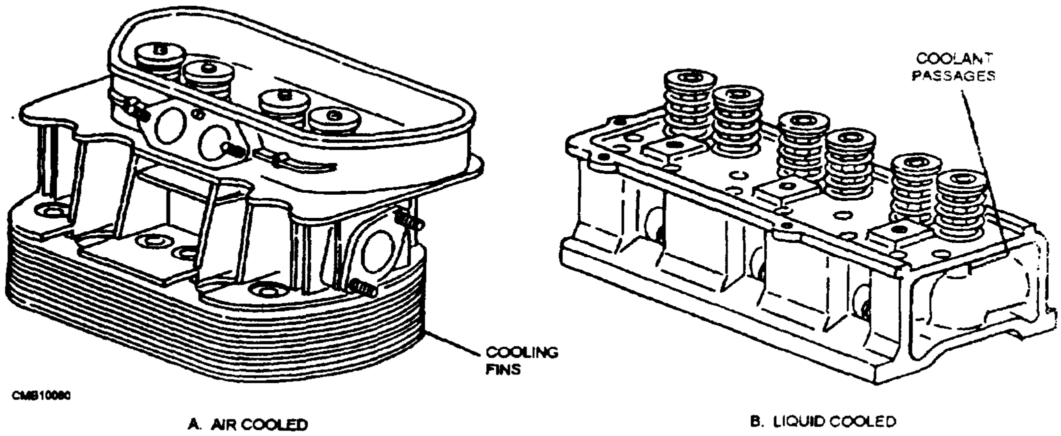


Figure 3-9.—Cylinder heads.

of aluminum since it needs the ability to dissipate large amounts' of heat. On air-cooled engines, the oil pan usually is made of cast aluminum, and it is covered with cooling fins. The oil pan on an air-cooled engine plays a key role in the removal of waste heat from the engine through its lubricating oil.

Cylinder Head

The cylinder head (fig. 3-9) provides combustion for the engine cylinders. It is built to conform to the arrangement of the valves: L-head, I-head, or others. Cylinder heads on liquid-cooled engines have been made almost exclusively from cast iron until recent years. Because weight has become an important consideration, a large percentage cylinder heads now are being made from aluminum. The cylinder heads on air-cooled engines are made exclusively from aluminum. This is due to the fact that aluminum conducts heat approximately three times as fast as cast iron. This is a critical consideration with air cooling.

In liquid-cooled engines. the cylinder (fig. 3-10) head is bolted to the top of the cylinder block to close the

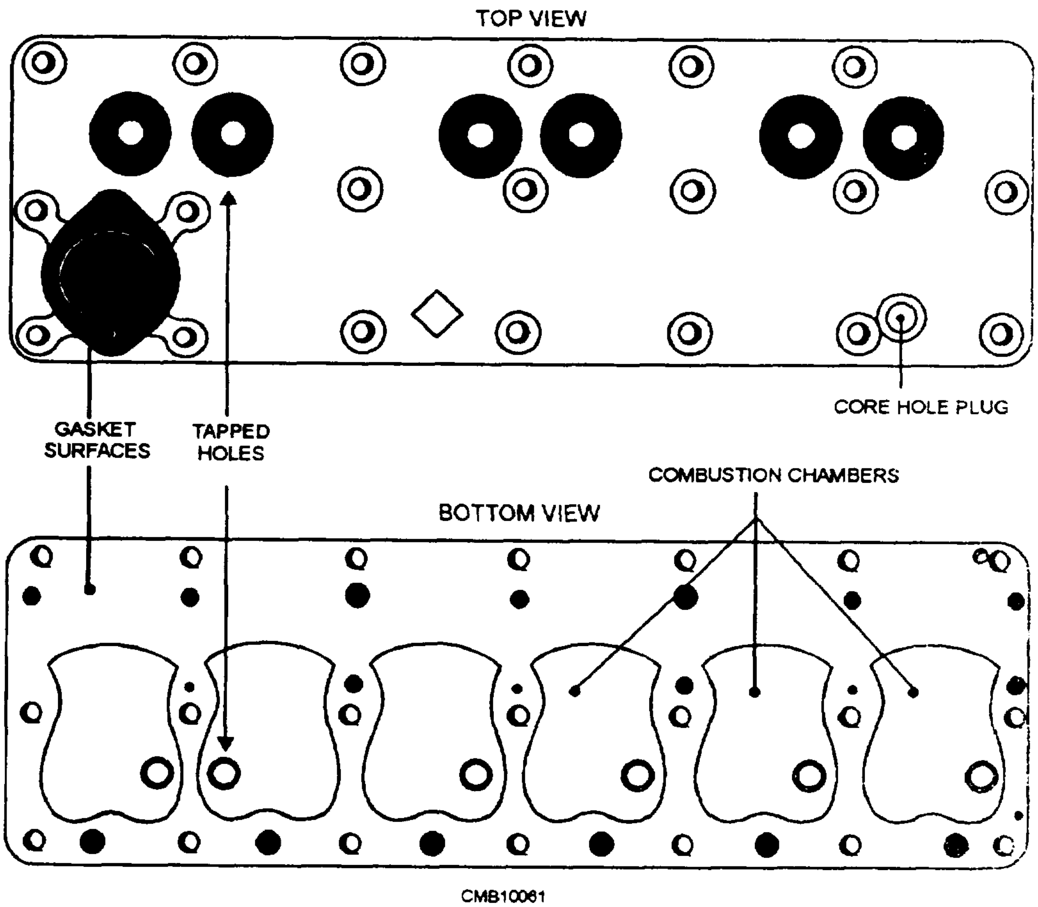


Figure 3-10.—Cylinder head for L-head engine.

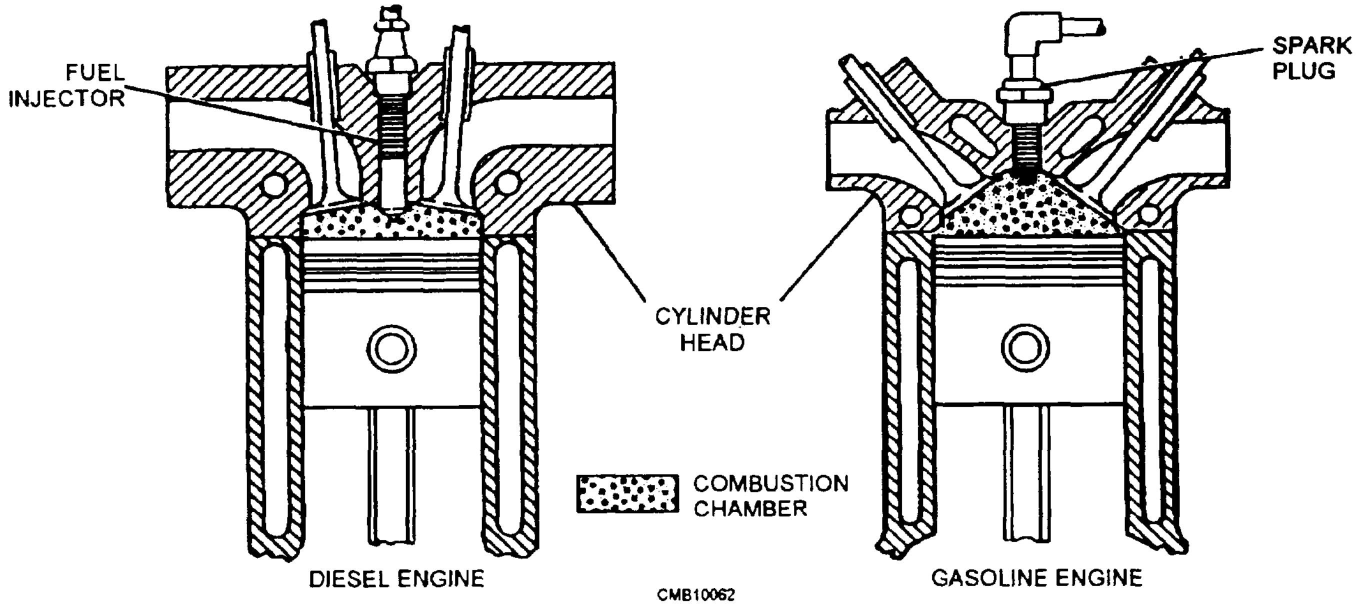


Figure 3-11.—Combustion chambers.

upper end of the cylinders and, in air-cooled engines, the cylinder heads are bolted to the top of the cylinders. This serves to provide a combustion chamber (fig. 3-11) for the ignition of the mixture and to hold the expansion forces of the burning gases so they may act on the piston. In a gasoline engine, there are threaded holes to position the spark plugs in the combustion chamber. On a diesel engine, there is a similar arrangement to position the fuel injectors. In a liquid-cooled engine, it also contains passages, matching those of the cylinder block, that allow cooling liquid to circulate in the head.

The I-head (overhead valve) type of cylinder head (fig. 3-12) contains not only water jackets for cooling spark plugs openings, valve pockets, and part of the combustion chamber, but it also contains and supports the valves and valve operating mechanisms. In this type of cylinder head, the water jackets must be large enough to cool not only the top of the combustion chamber but also the valve seats, valves, and valve operating mechanisms.

The cylinder heads are sealed (fig. 3-13) to the cylinder block to prevent gases from escaping. This is accomplished on liquid-cooled engines by the use of a head gasket. The head gasket is usually made of two sheets of soft steel that sandwich a layer of asbestos. Steel rings are used to line the cylinder openings. They are designed to hold the tremendous pressure created on the power stroke. Holes are cut in the gasket to match the coolant and lubrication feed holes between the cylinder head and the cylinder block. In an air-cooled engine, cylinder heads are sealed to the tops of the cylinders by soft metal rings. The lubrication system feeds oil to the heads through the pushrods.

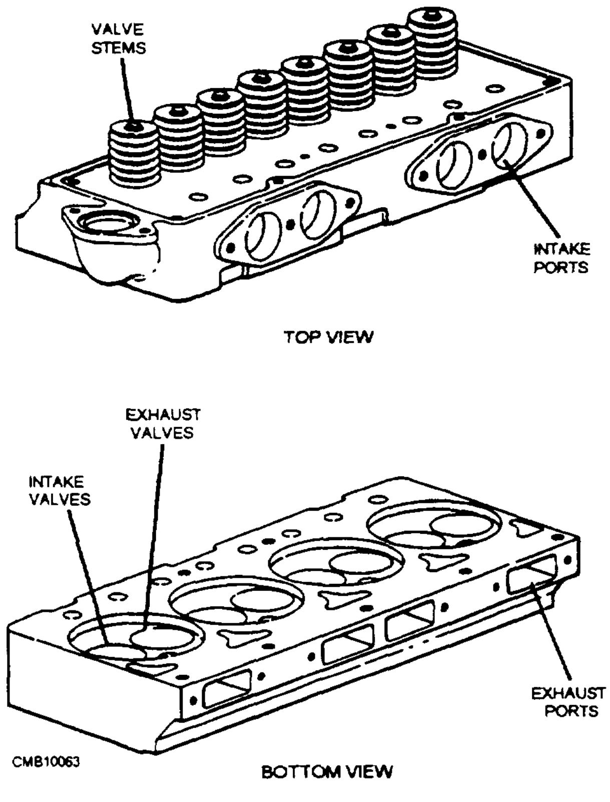


Figure 3-12.—Cylinder head for overhead valve engine.

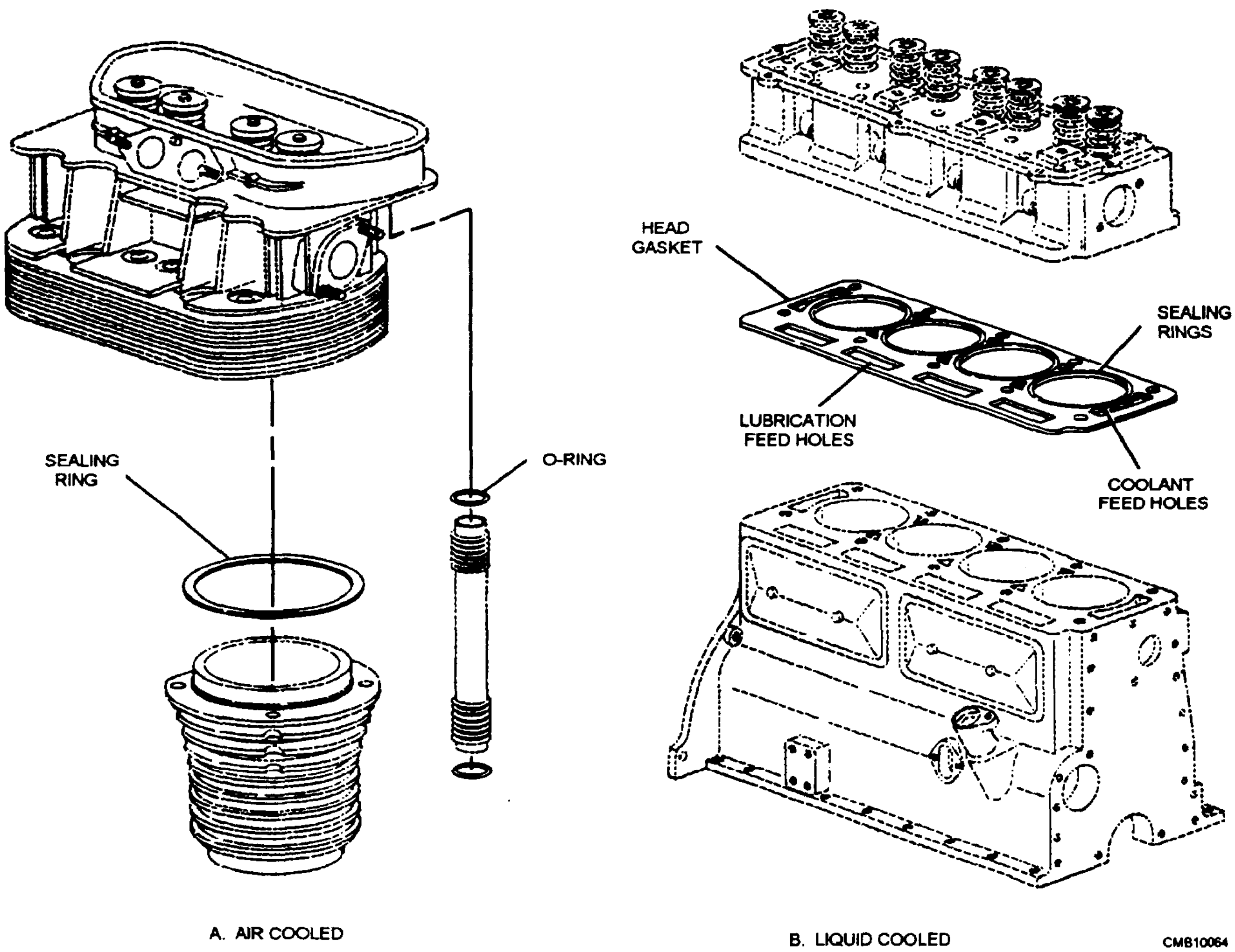


Figure 3-13.—Cylinder head sealing.

Exhaust Manifold

The exhaust manifold (fig. 3-14) connects all of the engine cylinders to the rest of the exhaust system. On L-head engines, the exhaust manifold bolts to the side of the engine block; and on overhead-valve engines, it bolts to the side of the cylinder head. It is usually made of cast iron, either singly or in sections. If the exhaust manifold is made properly, it can create a scavenging action that causes all of the cylinders to help each other get rid of the gases. Back pressure (the force that the pistons must exert to push out the exhaust gases) can be reduced by making the manifold with smooth walls and without sharp bends. Exhaust manifolds on vehicles today are constantly changing in design to allow the use of various types of emission controls. Each of these factors is taken into consideration when the exhaust manifold is designed, and the best possible manifold is manufactured to fit into the confines of the engine compartment.

Intake Manifold

The intake manifold on a gasoline engine carries the air-fuel mixture from the carburetor and distributes it to the cylinders. On a diesel engine, the manifold carries only air into the cylinders. The gasoline engine intake manifold (fig. 3-15) is designed with the following functions in mind:

- Deliver the air-fuel mixture to the cylinders in equal quantities and proportions. This is important for smooth engine performance. The lengths of the passages should be near to equal as possible to distribute the air-fuel mixture equally.

- Help to keep the vaporized air-fuel mixture from condensing before it reaches the combustion chamber. The ideal air-fuel mixture should be vaporized completely, as it enters the combustion chamber. This is very important. The manifold passages are designed with smooth

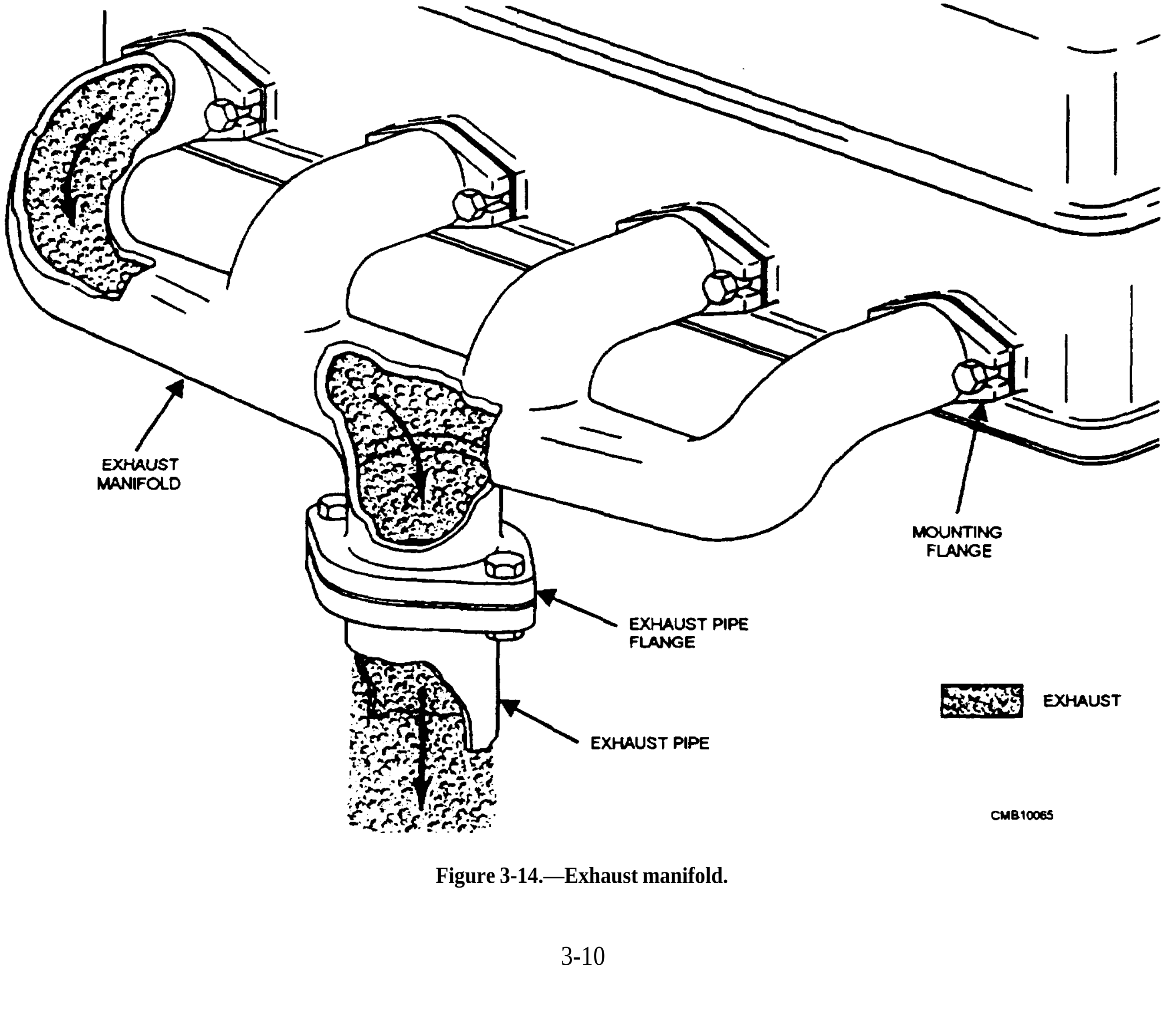


Figure 3-14.—Exhaust manifold.

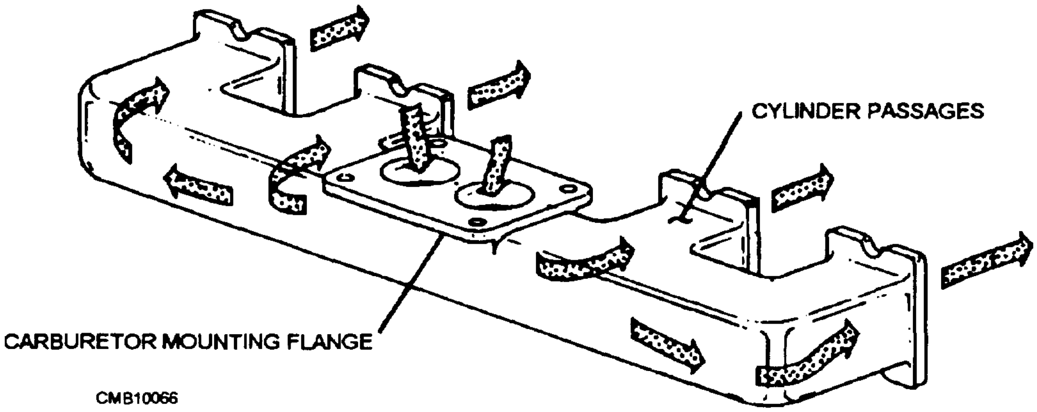


Figure 3-15.—Typical intake manifold.

walls and a minimum of bends that collect fuel to reduce the condensing of the mixture. Smooth flowing intake manifold passages also increase volumetric efficiency.

- Aid in the vaporization of the air-fuel mixture. To do this, provide the intake manifold a controlled system of heating. This system of heating must heat the mixture enough to aid in vaporization—without heating it to the point of reducing volumetric efficiency.

The intake manifold on an L-head engine is bolted to the block, whereas the overhead-valve engine has the intake manifold bolted to the side of the cylinder head.

Intake manifolds can be designed to provide optimum performance for a given speed range by varying the length of the passages (fig. 3-16). The inertia of the moving intake mixture causes it to bounce back and forth in the intake manifold passage from the end of one intake stroke to the beginning of the next intake stroke. If the passage is the proper length so the next intake stroke is just beginning as the mixture is rebounding, the inertia of the mixture causes it to ram itself into the cylinder. This increases the volumetric efficiency of the engine in the designated speed range. It should be noted that the ram manifold serves no purpose outside its designated speed range.

As stated earlier, providing controlled heat for the incoming mixture is very important for good performance. The heating of the mixture may be accomplished by doing one or both of the following:

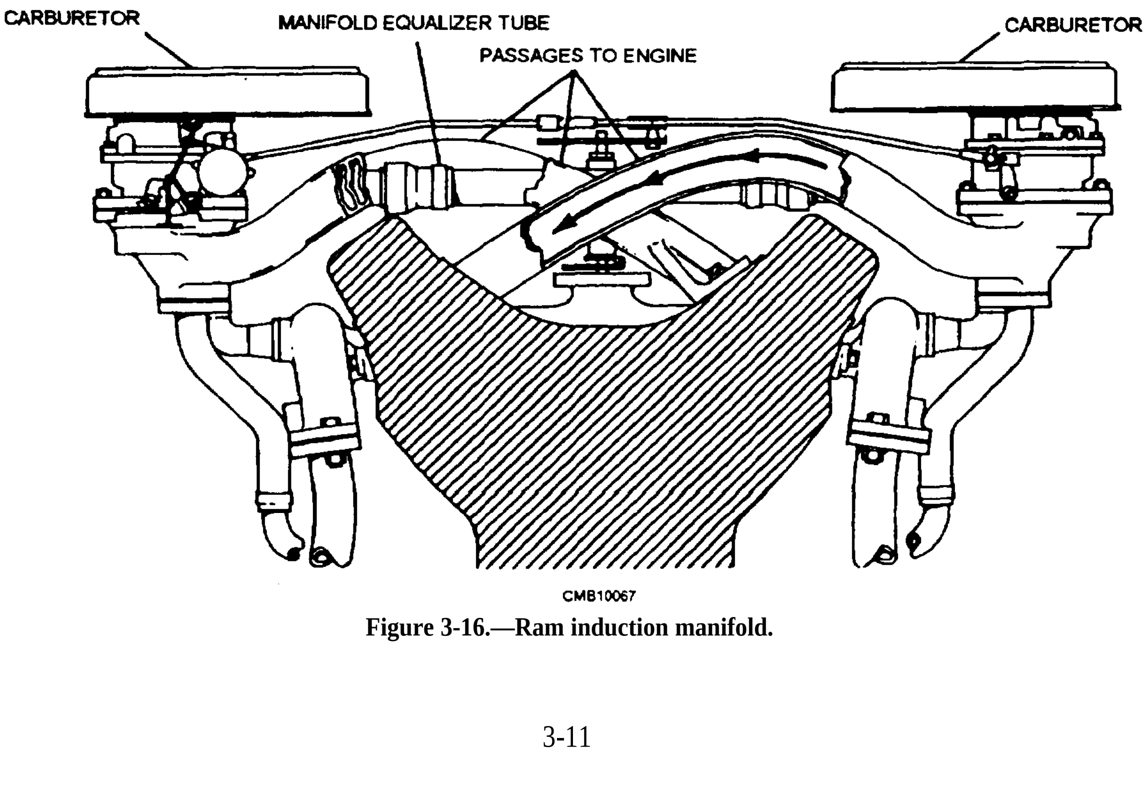


Figure 3-16.—Ram induction manifold.

- Directing a portion of the exhaust through a passage in the intake manifold (fig. 3-17). The heat from the exhaust transfers and heats the mixture. The amount of exhaust that is diverted into the intake manifold heat passage is controlled by the manifold heat control valve.

- Directing the engine coolant, which is heated by the engine, through the intake manifold on its way to the radiator (fig. 3-18).

Gaskets

Gaskets (fig. 3-19), otherwise known as static seals, are used to form pressure-tight joints between stationary members. They are usually made of a deformable material in the shape of a sheet or ring, which conforms to the irregularities in mating surfaces when compressed. Steel, aluminum, copper, asbestos, cork, synthetic rubber, paper, and felt are just a few of the materials that are used singly or in combination to produce leakproof joints. The proper material used in gasket construction depends on the temperature, type of fluid to be contained, smoothness of mating surfaces, fastener tension, pressure of the substance to be confined, material used in construction of mating parts, and part clearance relationship. Some of the most common engine gaskets are as follows:

- **CYLINDER HEAD GASKET** which is placed between the cylinder head and the cylinder block to maintain a gastight and coolant-tight seal. It is made in the form of two thin plates of soft metal with asbestos tilling between them.

- **INTAKE AND EXHAUST GASKETS** are made from asbestos and formed to a desired shape. Some of them are metal-covered and similarin construction to a cylinder head gasket.

- **OIL PAN GASKET** is generally made from pressed cork. It may be made in one piece but is often made as two pieces.

Gaskets also can be formed by using a silicone sealant. This type is formed by applying sealant from a squeeze tube to the mating surfaces and allowing it to dry, forming a sealed flexible joint. This type of seal is becoming more popular on modern vehicles.

Oil Seals

Oil seals used in vehicle assembly are designed to prevent leakage between rotating and non-rotating

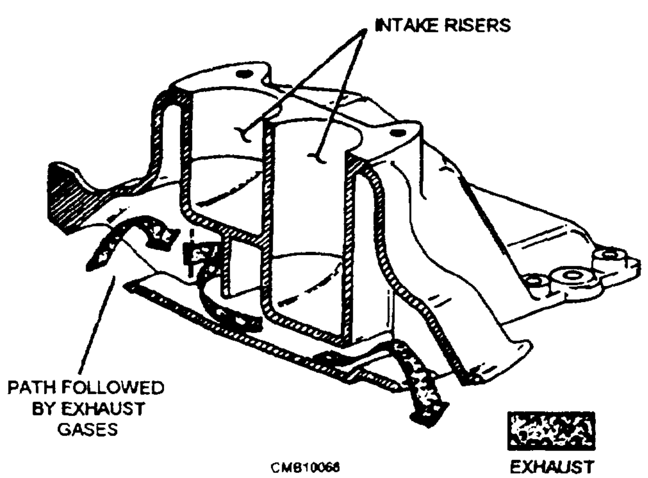


Figure 3-17.—Exhaust-heated intake manifold.

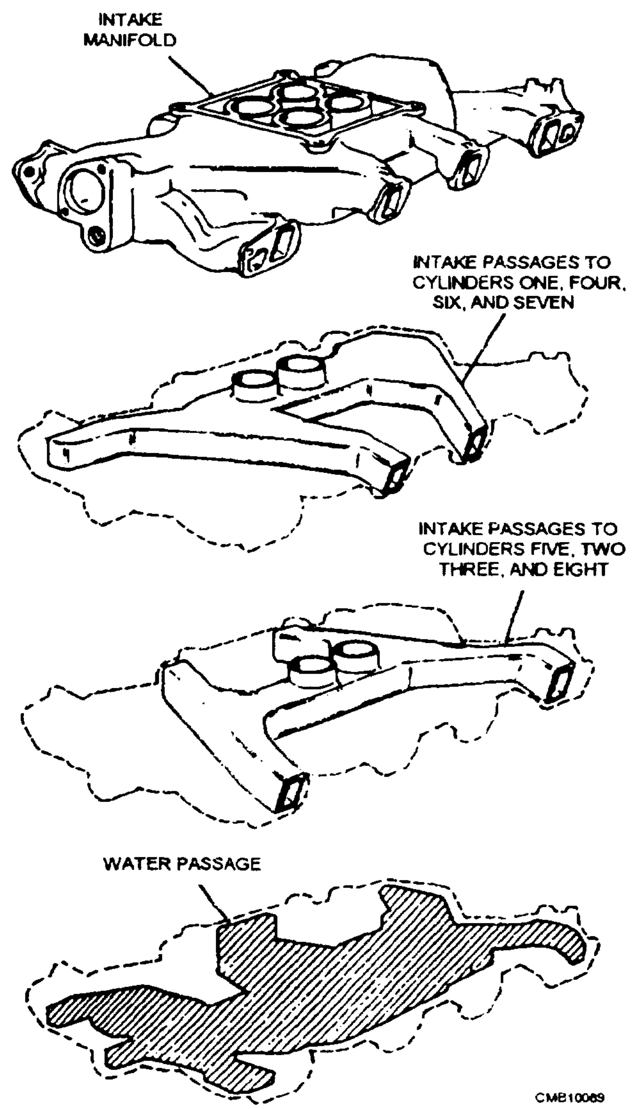


Figure 3-18.—Water-heated intake manifold.

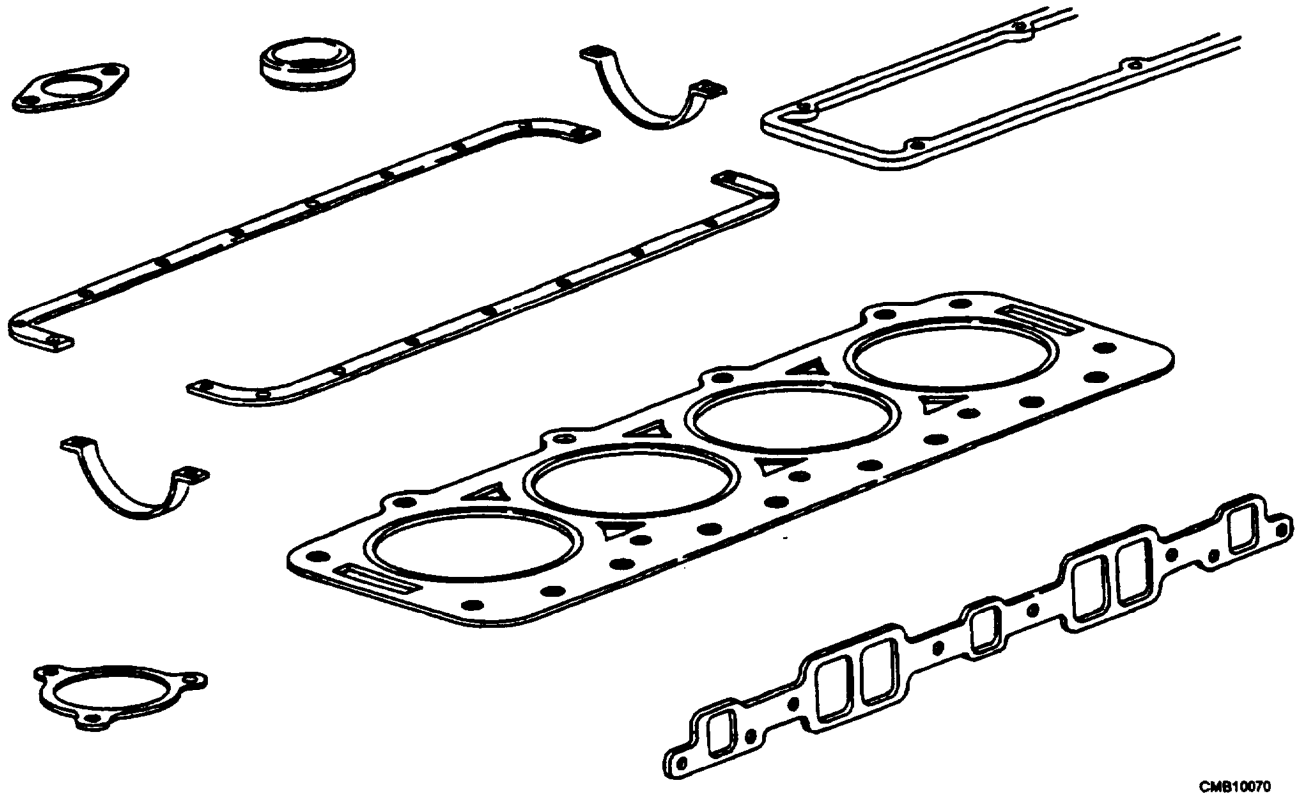


Figure 3-19.—Typical gaskets.

members. Two basic types of oil seals used on vehicles today are synthetic rubber seals and wick seals. Each is discussed below.

- **SYNTHETIC RUBBER SEALS.** The synthetic rubber seal (fig. 3-20) is the most common type of oil seal. It is composed of a metal case used to retain its shape and maintain rigidity. A rubber element is bonded to the case, providing a sealing lip or lips against the rotating shaft. Different types of oil seal designs are shown in figure 3-20. A coil spring, sometimes called a garter spring, is used to hold the rubber element around the shaft with a controlled force. This allows the seal to conform to minor shaft runout. Some synthetic rubber seals fit into bores mounted around the shaft This type is generally a split design and does not require a metal case or garter spring. Figure 3-20 shows the effects of pressure on lip seals. The internal pressure developed during operations forces the sealing lips tighter against the rotating shaft. This type of seal only operates effectively against fluid pressure from one direction. Leather also is used as a lip seal. In this configuration, the inside diameter of the seal is smaller than the shaft As the shaft is installed, the seal bows outward to form a lip seal.

- **WICK SEALS.** The wick seal (fig. 3-21) is made of graphite-impregnated asbestos. Wicking is sometimes used to control oil leakage. This seal conforms to the recess in which it is installed. When using this type of seal, use a knurl finish on the rotating shaft. The oil is contained between the knurls and seal, which rub together. As the shaft rotates, the oil is driven back by the propeller effect of the seal and knurl finish. An oil slinger sometimes is used with wick seals. The oil slinger is a raised washerlike area on the shaft. As oil meets the slinger, it is propelled outward by centrifugal force. A catch trough then is used to collect the oil and return it to the sump.

As you gain experience in the mechanical field, you will be able to recognize the different types of seals and how they work to prevent leaks. Other types of seals are discussed in a later module.

MOVING PARTS OF AN ENGINE

The moving parts of an engine serve an important function—turning heat energy into mechanical energy. They further convert reciprocal motion into rotary

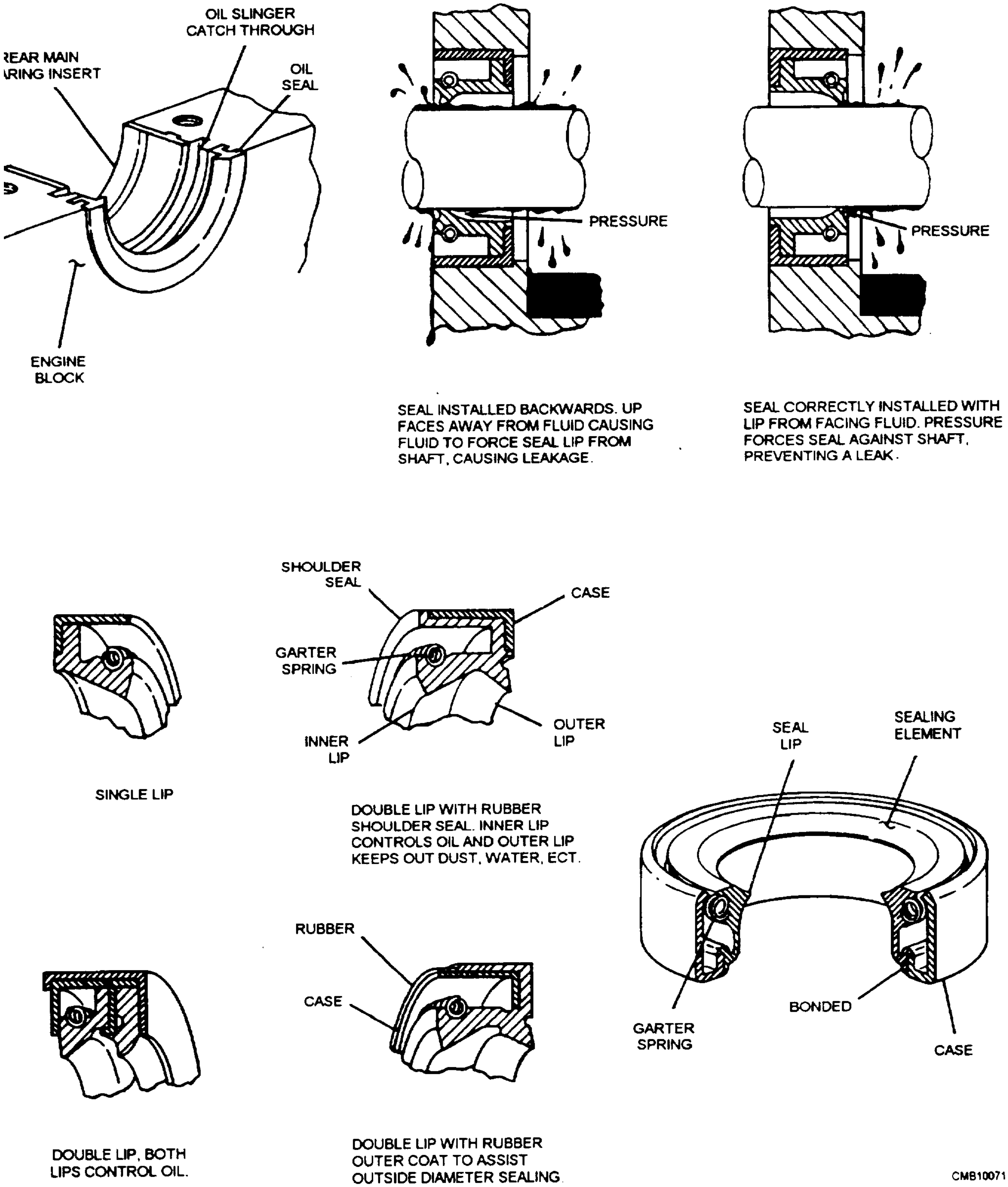


Figure 3-20.—Synthetic rubber oil seals.

motion. The principal moving parts are the piston assembly, the connecting rods, the crankshaft assembly (including flywheel and vibration dampener), the camshaft, the valves, and the gear train.

Burning of the air-fuel mixture within the cylinder exerts a pressure on the piston, thus pushing the cylinder down. The action of the connecting rod and crankshaft converts this downward motion to a rotary motion.

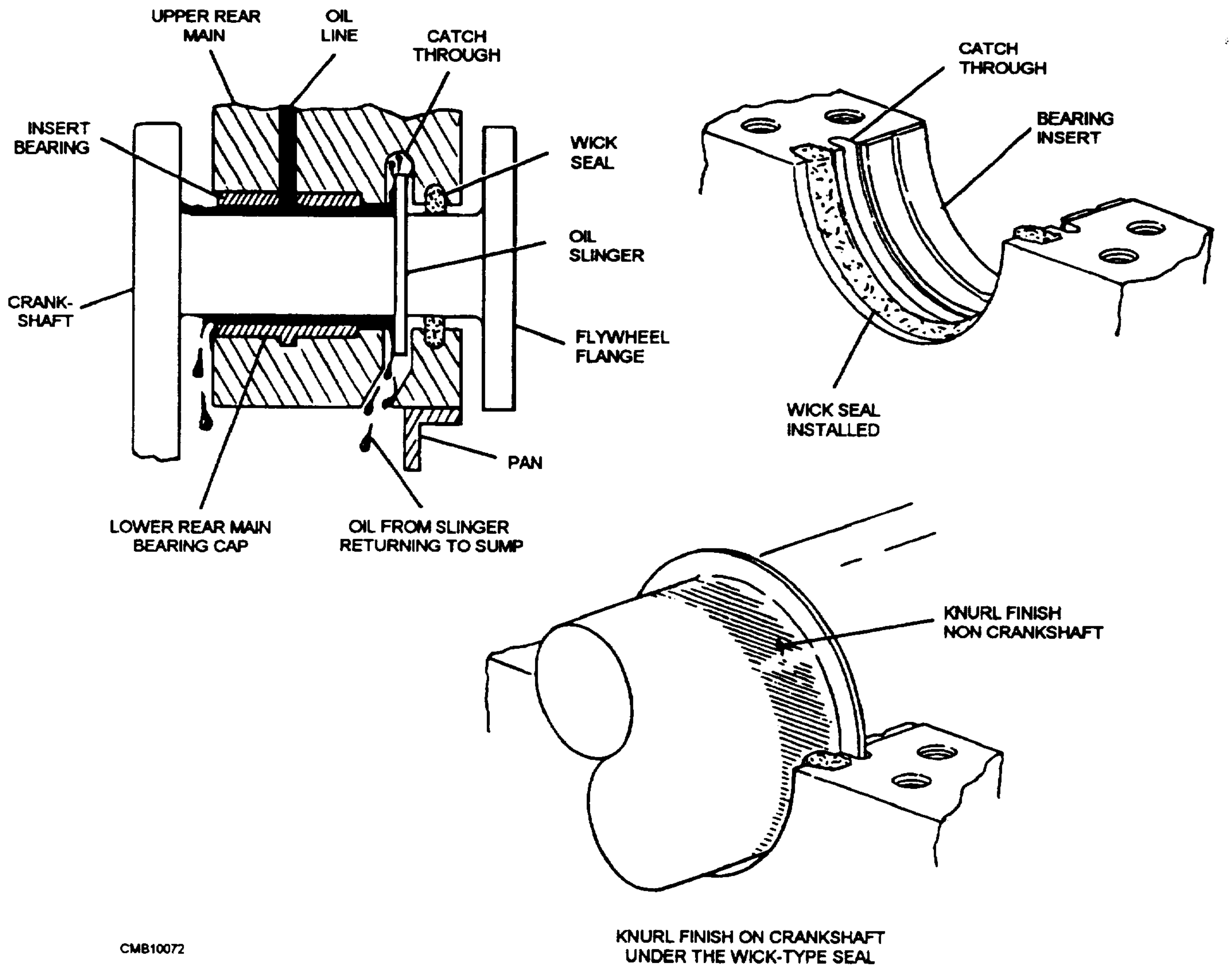


Figure 3-21.—Wick seals.

Piston Assembly

Pistons (fig. 3-22) are usually made of an aluminum alloy. They are a sliding fit in the cylinders. This serves several purposes as follows:

- Transmits the force of combustion to the crankshaft through the connecting rod.
- Acts as a guide for the upper end of the connecting rod.
- Serves as a carrier for the piston rings that are used to seal the compression in the cylinder.

The piston must withstand incredible punishment under temperature extremes. The following are

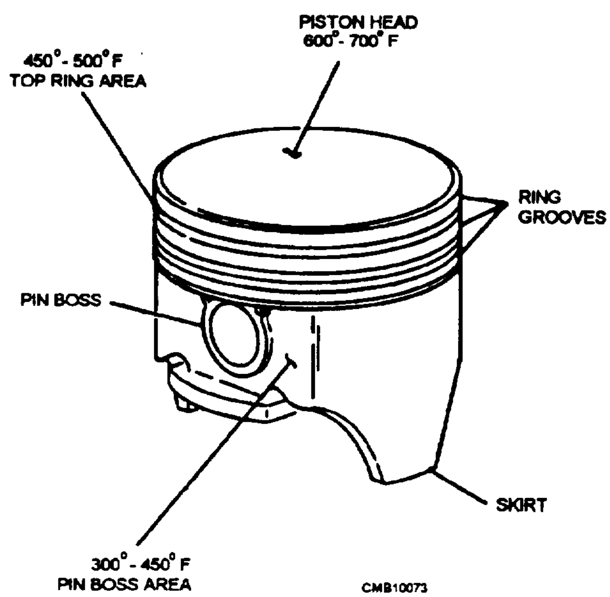


Figure 3-22.—Piston.

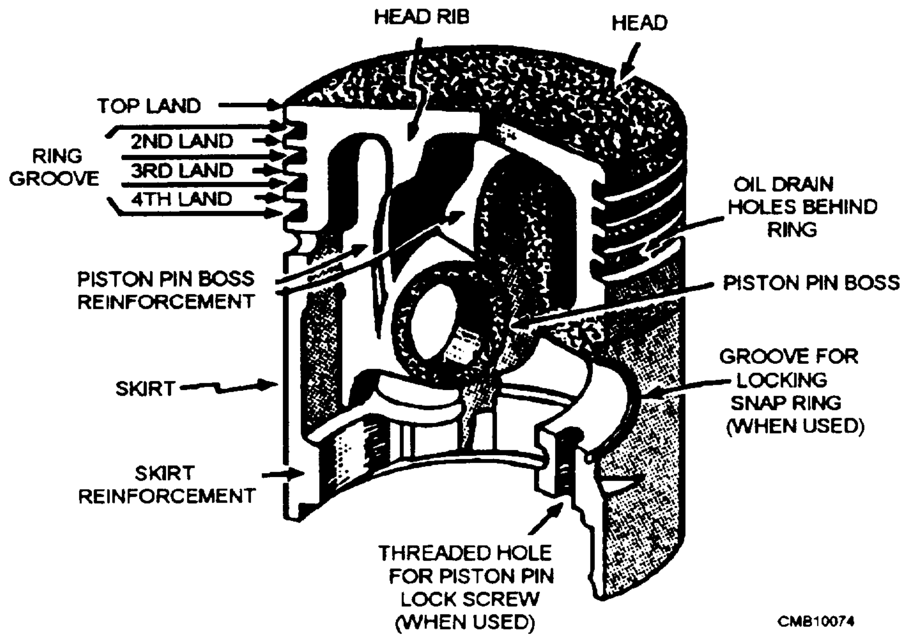


Figure 3-23.—The parts of a piston.

examples of conditions that a piston must withstand at normal highway speed:

- As the piston moves from the top of the cylinder to the bottom (or vice versa), it accelerates from a stop to a speed approximately 50 mph at midpoint, and then decelerates to a stop again. It does this approximately 80 times per second.
- The piston is subjected to pressures on its head in excess of 1,000 psi.
- The piston head is subjected to temperatures well above 600°F.

The structural components of the pistons are the **HEAD, SKIRT, RING GROOVES,** and **LANDS** (fig. 3-23); however, all pistons do not look like the typical one shown here. Some have differently shaped heads. Diesel engine pistons usually have more ring grooves and rings than the pistons of a gasoline engine. Some of these rings may be installed below as well as above the **WRIST** or **PISTON PIN** (fig. 3-24).

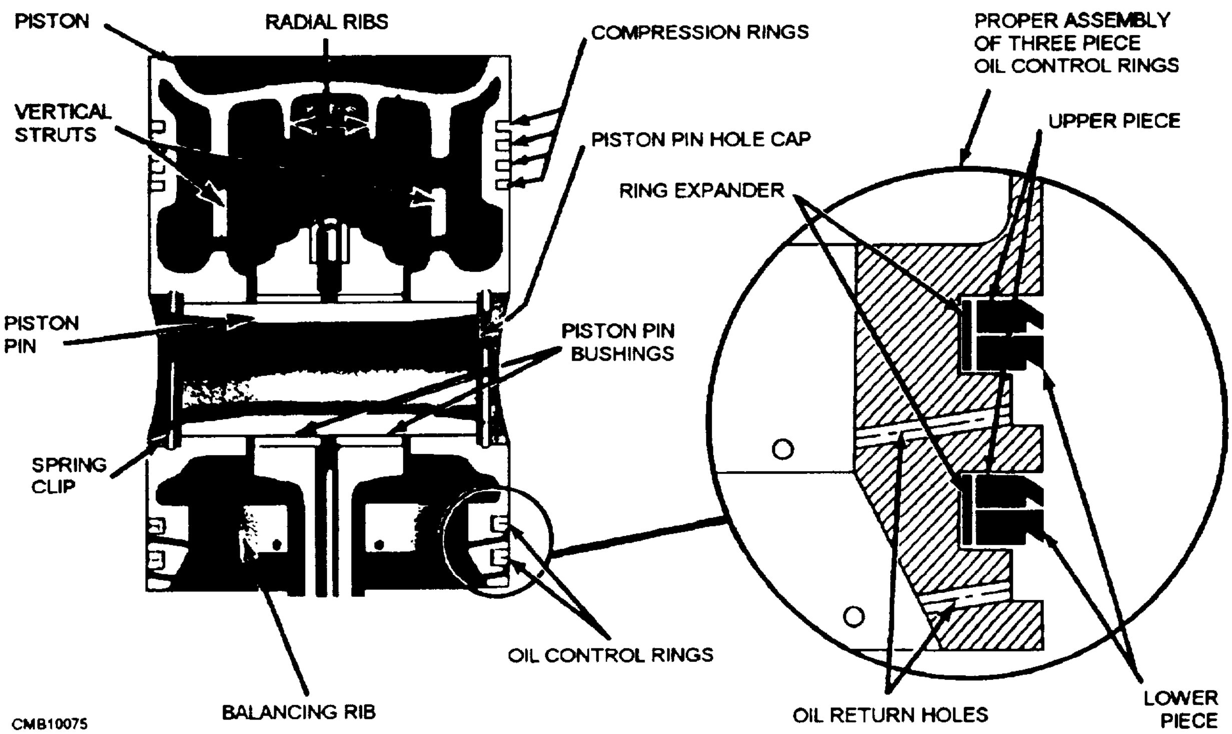


Figure 3-24.—Diesel piston assembly.

Fitting pistons into the cylinder properly is very important. Because metal expands when heated, space must be provided for lubricants between the pistons and the cylinder walls. Pistons must have features built into them to control expansion. Without these features, pistons would fit loosely in the cylinders when cold, and then bind in the cylinders, as they are warmed up. This is the problem with aluminum because it expands so much. The pistons (fig. 3-25) may be designed with the following features to control expansion:

- It is obvious that the crown of the piston gets hotter than the rest of the piston. To prevent it from expanding to a larger size than the rest of the piston, it is machined to a diameter that is approximately 0.03 to 0.04 of an inch smaller than the skirt area.
- One way to control expansion in the skirt area is to cut a slot up the side of the skirt. As a split-skirt piston warms up, the split merely closes, thereby keeping the skirt from expanding outward and binding the piston in the cylinder.
- Another variation of the split-skirt piston is the T-slot piston. The T-slot piston is similar to the split-skirt piston with the addition of a horizontal slot that retards heat transfer from the piston head to the piston skirt.
- Some aluminum pistons have steel braces cast into them to control expansion.

The skirt, or bottom part, of the piston runs much cooler than the top; therefore, it does not require as much clearance as the head.

The piston is kept in alignment by the skirt, which is usually **CAM-GROUND** (elliptical in cross section), as shown in figures 3-26 and 3-27. By making the piston egg-shaped, it is able to fit the cylinder better throughout its operational temperature range. Cam-ground pistons are machined so their diameter is smaller and more parallel to the piston pin axis than it is perpendicular to it. When the piston is cold, it is big enough across the larger diameter to keep from rocking. As it warms up, it expands across its smaller diameter at a much higher rate than at its larger diameter. This tends to make the piston round at operating temperature. The walls of the skirt are cut away as much as possible to reduce weight and to prevent excessive expansion during engine operation. Virtually all pistons in automotive applications are cam ground.

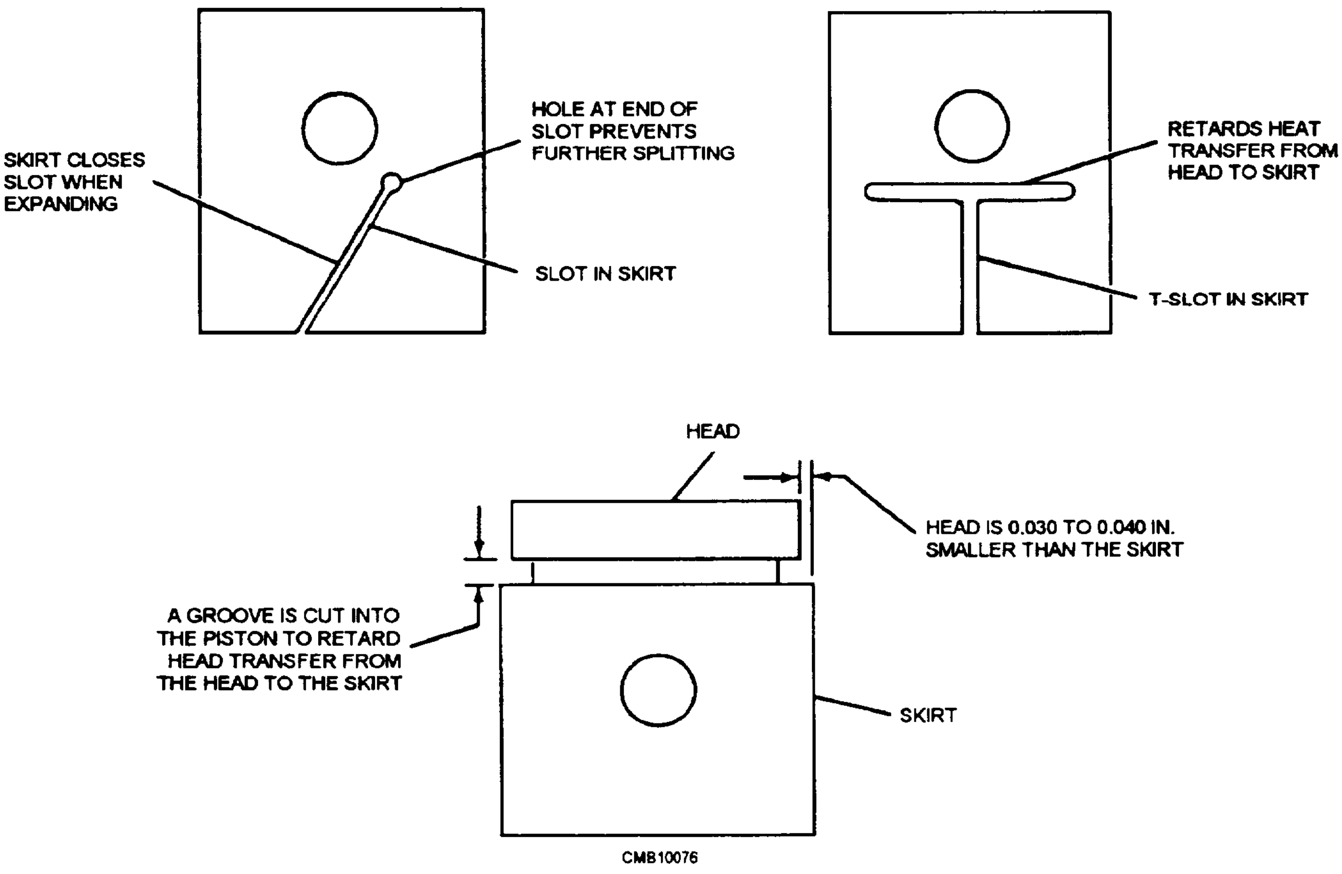


Figure 3-25.—Controlling piston expansion.

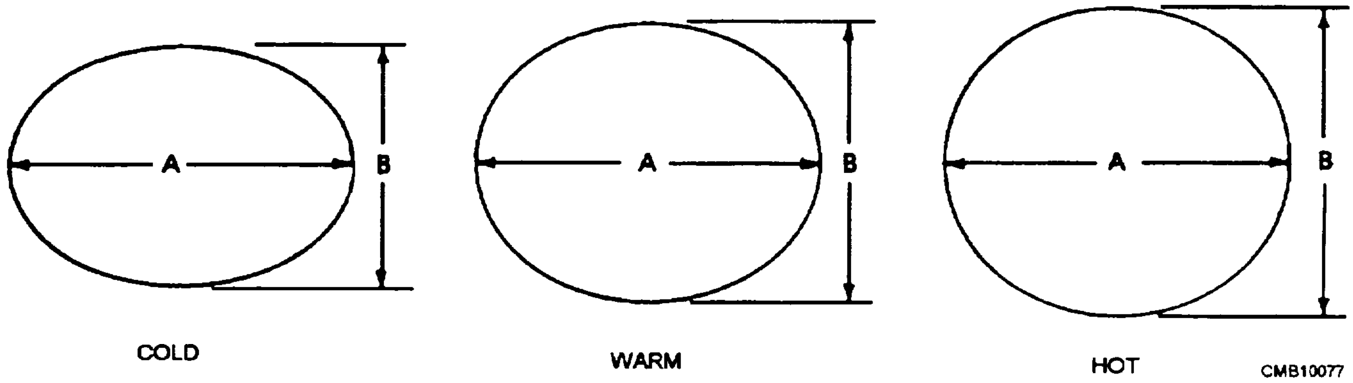


Figure 3-26.—Cam-ground piston action.

There are two types of piston skirts in most **engines—FULL TRUNK** and **PARTIAL SKIRTED (SLIPPER)** (fig. 3-28). The full trunk type of skirt has a full cylindrical shape with hearing surfaces parallel to those of the cylinder. This gives it more strength and better control of the oil film. The partial skirt or slipper skirt has considerable relief on the sides of the skirt. Removal of the skirt in these areas serves the following purposes:

- Lightens the piston, which, in turn, increases the speed range of the engine.
- Reduces the contact area with the cylinder wall, which reduces friction.
- Allows the piston to be brought down closer to the crankshaft without interference with its counterweights.

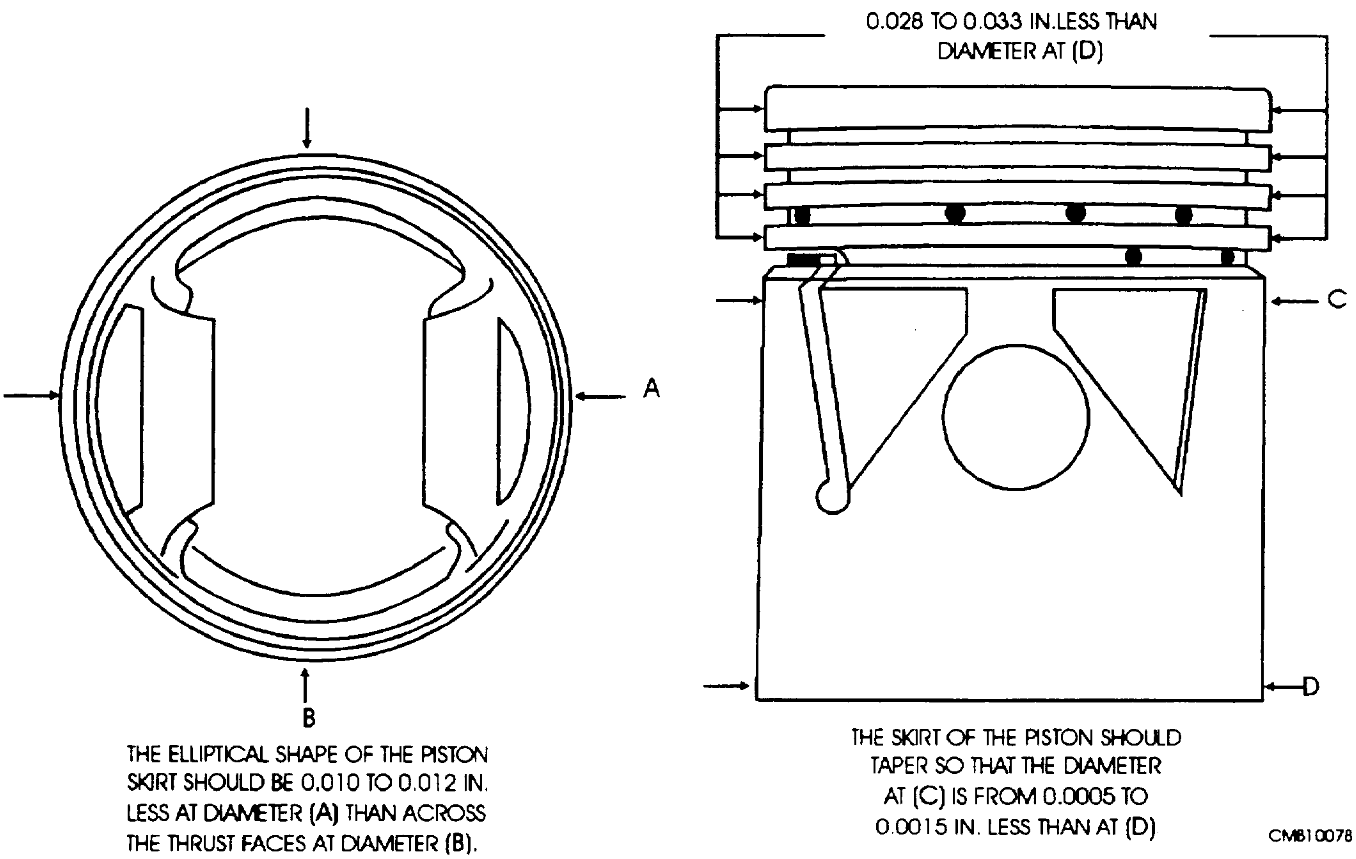


Figure 3-27.—Cam-ground piston.

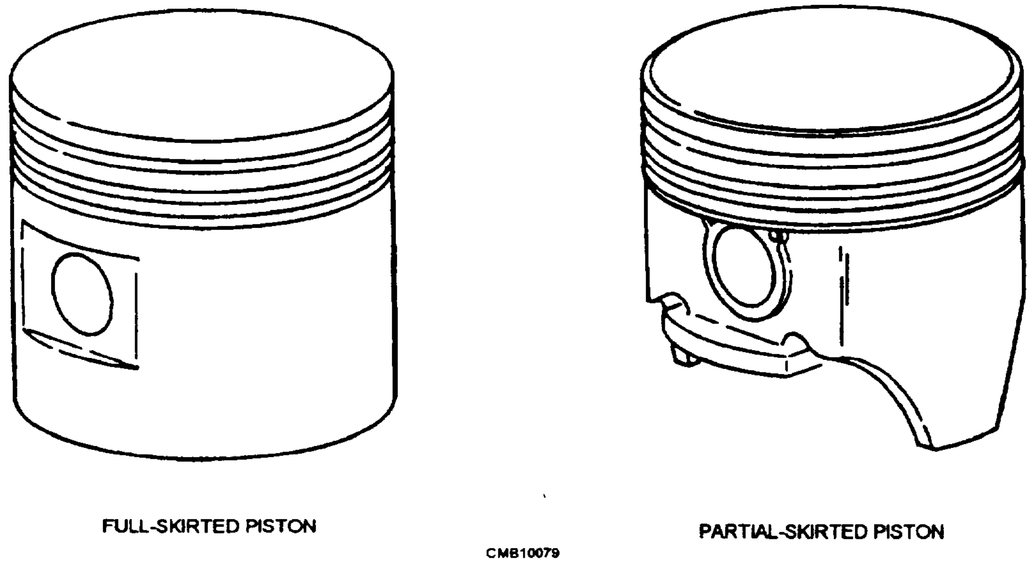


Figure 3-28.—Full- and partial-skirted pistons.

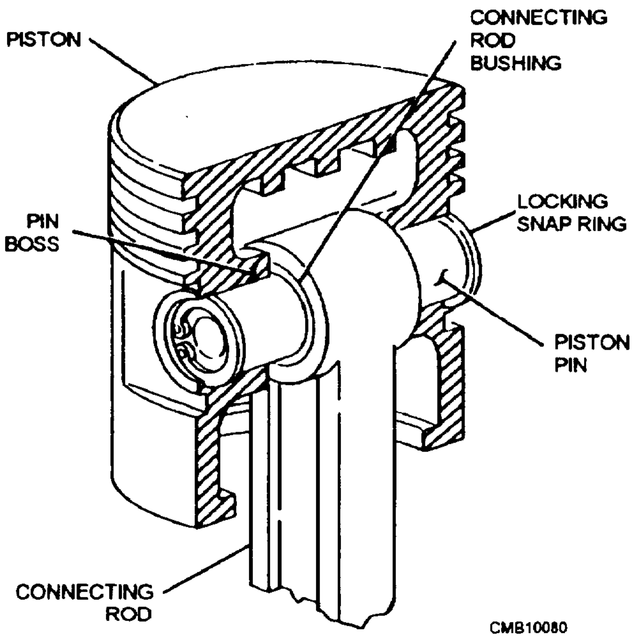


Figure 3-29.—Piston pin.

The piston pin (fig. 3-29) serves to connect the piston to the connecting rod. It passes through the pin bosses in the piston and the upper end of the connecting rod. The piston pin must be hard to provide the desired wearing qualities. At the same time, the piston pin must not be too brittle. A case-hardened steel pin is the best to satisfy the overall requirements of a piston pin. Case hardening is a process that hardens the surface of the steel to any desired depth. The pin is also hollow to reduce the overall weight of the reciprocating mass. They are lubricated by splash from the crankcase or by pressure through passages bored in the connecting rod.

There are three methods used for fastening a piston to the connecting rod. The following are the three different types of piston pins (fig. 3-30):

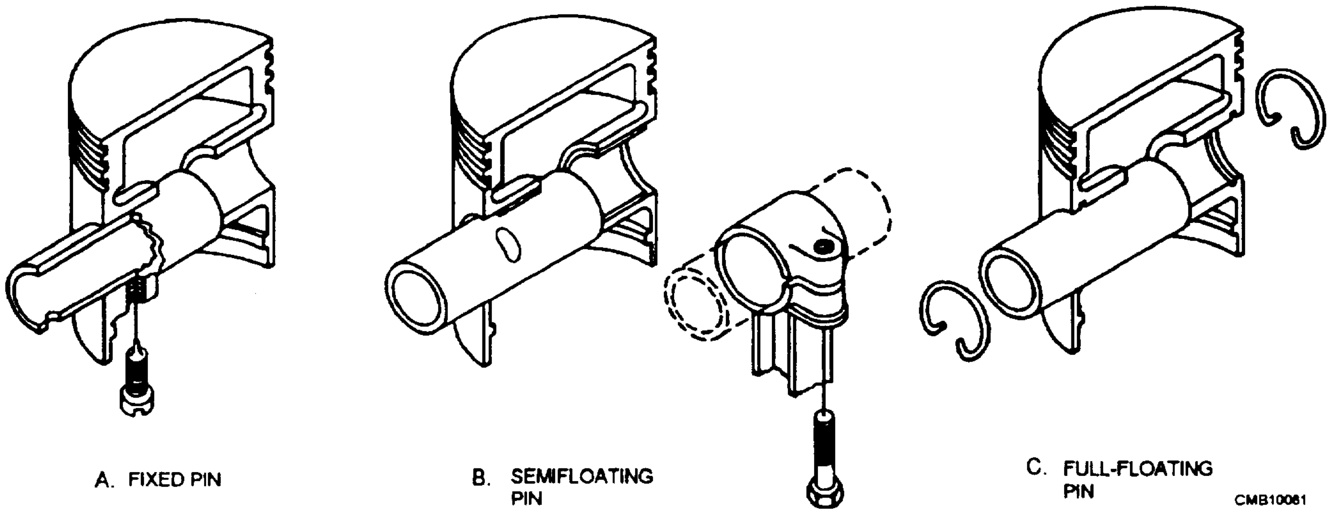


Figure 3-30.—Types of piston pins.

- An **ANCHORED,** or fixed, piston pin is locked into the piston pin bosses by a screw. The rod pivots freely on the connecting rod, which is fitted with a bronze bushing.
- A **SEMIFLOATING** pin is locked to the connecting rod by a screw or by friction. The pin pivots freely in the piston pin bosses.
- The **FULL-FLOATING** piston pin pivots freely in the connecting rod and piston pin bosses. The outer ends of the piston pins are fitted with lock rings to keep the pin from sliding out and contacting the cylinder walls.

Piston rings serve three important functions (fig. 3-31). They provide a seal between the piston and the cylinder wall to keep the force of the exploding gases from leaking into the crankcase from the combustion chamber. Blow-by is detrimental to engine performance because the force of the exploding gases merely bypasses the piston, rather than push down on it. It also contains the lubricating oil. They keep the lubricating oil from passing the piston and getting into the combustion chamber from the crankcase. Also, they provide a solid bridge to conduct heat from the piston to the cylinder wall. About one third of the heat absorbed by the piston passes to the cylinder wall through the piston rings.

Piston rings are secured to the piston by fitting into grooves. They are split to allow for installation and expansion, and they exert pressure on the cylinder walls when installed. They fit into grooves that are cut into the piston and are allowed to float freely in these grooves. A piston ring that is formed properly, working in a cylinder that is within limits for roundness and size, exerts an even pressure and a solid contact with the cylinder wall around the entire circumference. There are two basic classifications of piston rings. The **COMPRESSION RING** (fig. 3-32) that seals the force of the exploding mixture into the combustion chamber and the **OIL CONTROL RING** (fig. 3-32) that keeps engine lubricating oil from getting into the combustion chamber. These rings are arranged on the piston in three basic configurations (fig. 3-33). They are as follows:

- The three-ring piston has two compression rings from the top, followed by one oil control ring—the most common configuration.

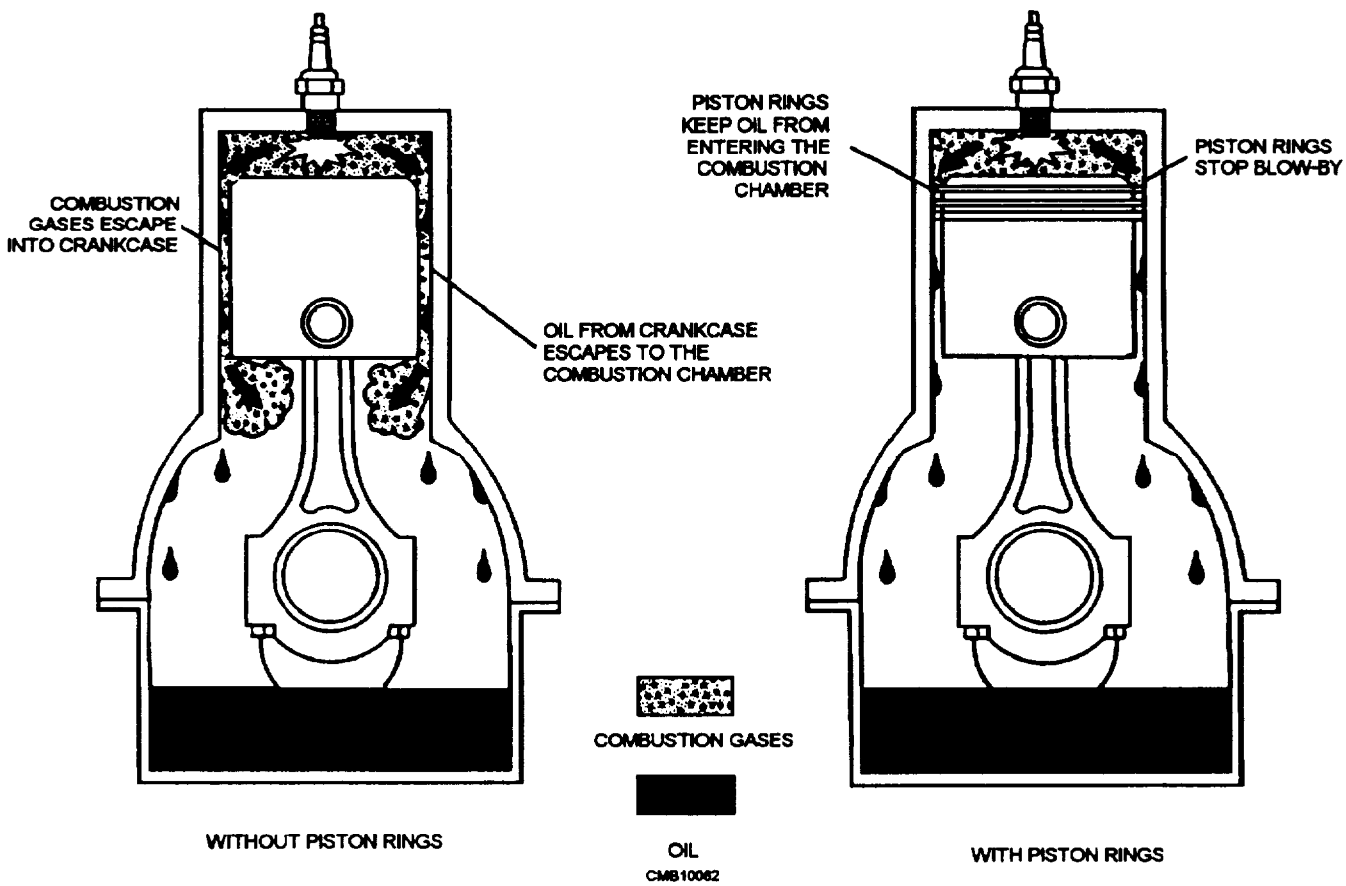


Figure 3-31.—Purpose of piston rings.

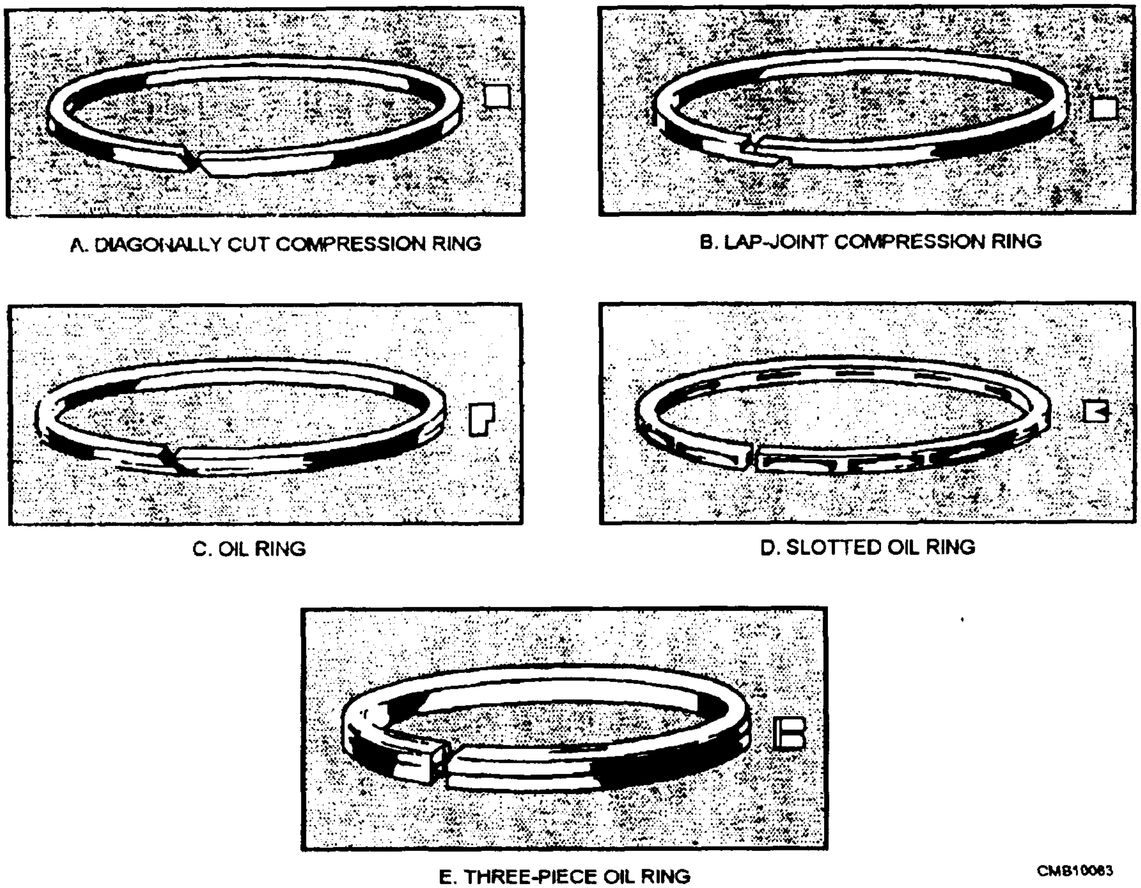


Figure 3-32.—Types of piston rings.

- The four-ring piston has three compression rings from the top, followed by one oil control ring. Commonly used on diesel engines because they are more prone to blow-by. This is due to the much higher pressures generated during the power stroke.
- The four-ring piston has two compression rings from the top, followed by two oil control rings. The bottom oil control ring may be located above or below the piston pin. This is not very common in current engine design.

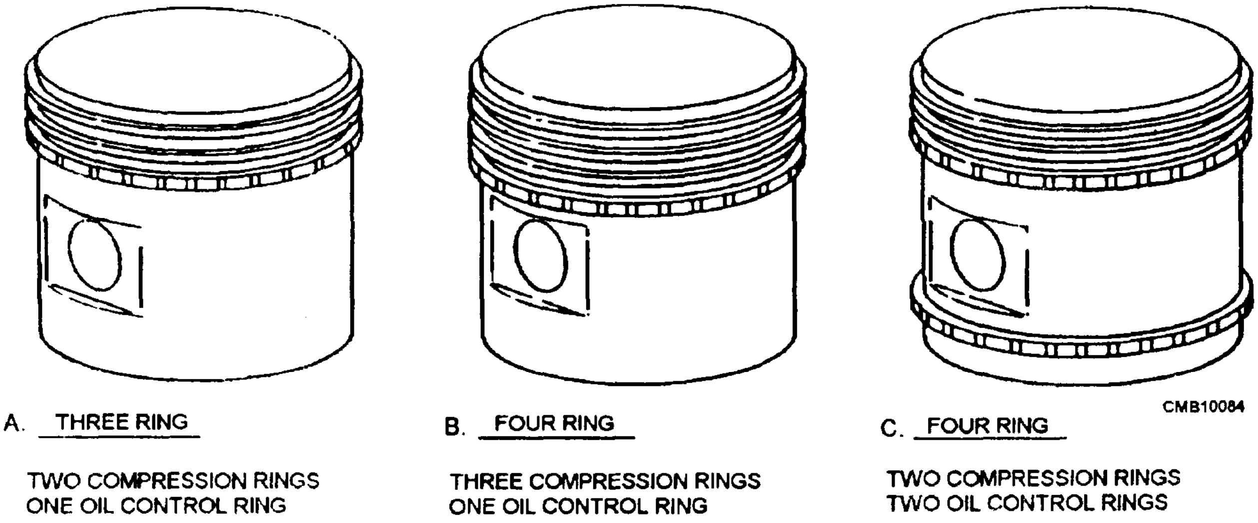


Figure 3-33.—Configurations of piston rings.

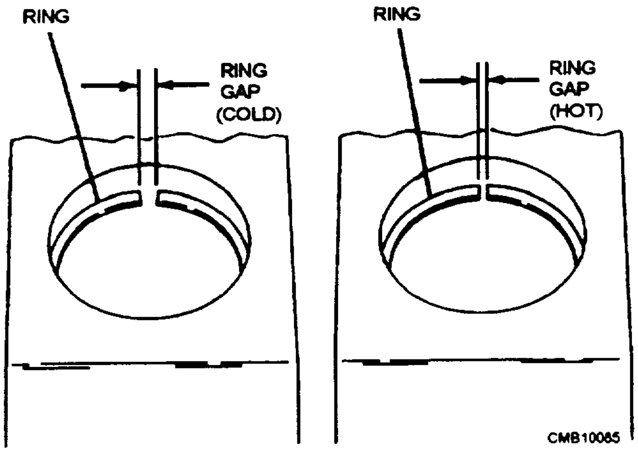


Figure 3-34.—Ring gap.

There is an additional groove cut into the piston just above the top ring groove. The purpose of this groove is to divert some of the intense heat that is absorbed by the piston head away from the top ring. This groove is called a **HEAT DAM.**

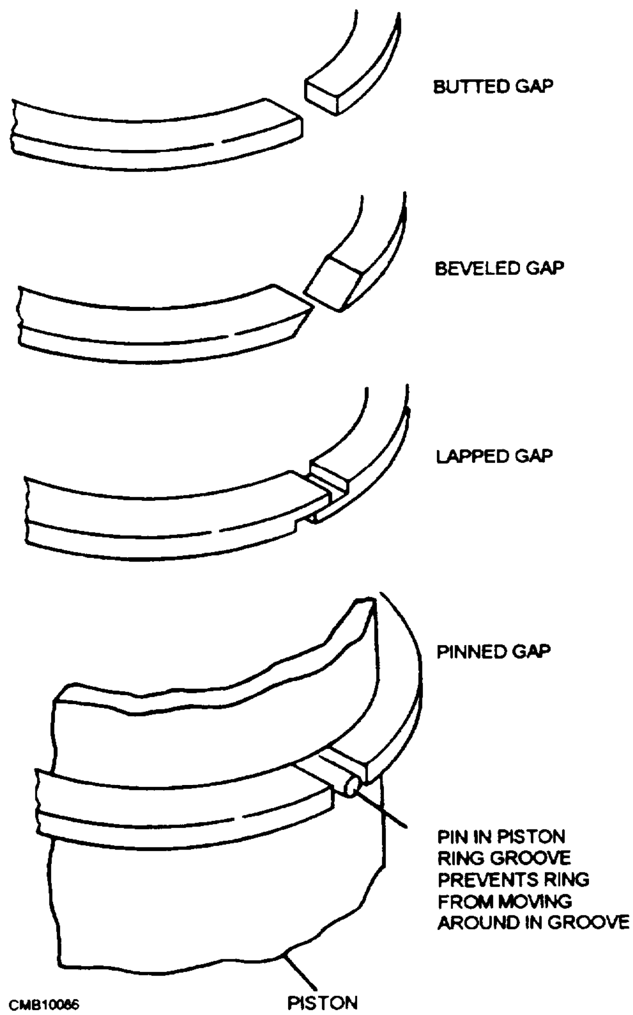


Figure 3-35.—Ring gap variations.

RING GAP (fig. 3-34) is the split in the piston ring. This is necessary for installing the ring on the piston and allowing for expansion from heating. The gap must be such that there is enough space so the ends do not come together, as the ring heats up. This would cause the rings to break. There are a few variations of ring gap joints (fig. 3-35). Two-cycle engines usually have pins in their ring grooves to keep the gap from turning. This is important because the ring would break if the ends were allowed to snap into the inlet or exhaust ports. Staggering the ring gap is also important as it prevents blow-by. A significant amount of total blow-by at the top ring will be from the ring gap. For this reason, the top and second compression rings are assembled to the piston with their gaps 60-degrees offset with the first ring gaps.

Rings must also be fitted for the proper side clearance (fig. 3-36). This clearance varies in different types and makes of engines; however, in a diesel engine, the rings must be given greater clearance than in a gasoline engine. If too much side clearance is given the rings, excessive wear on the lands will result. If there is too little side clearance, expansion may cause the lands to break.

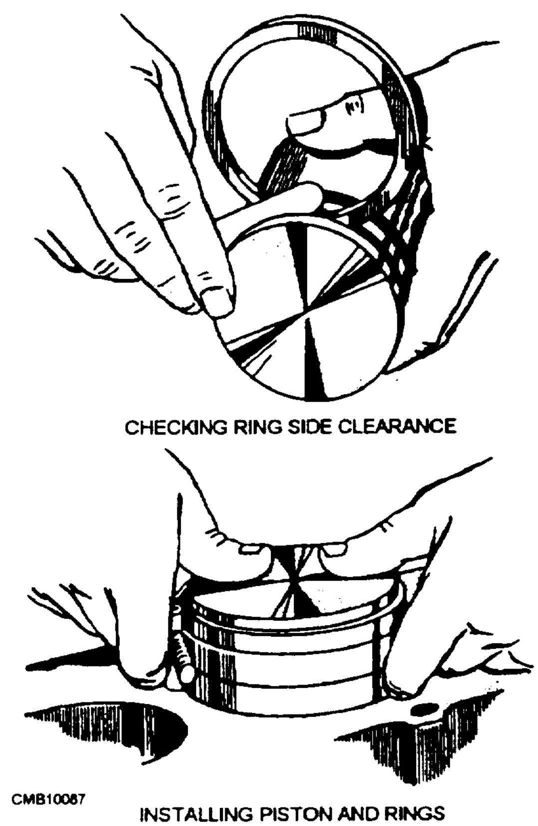


Figure 3-36.—Fitting piston ring and installing piston.

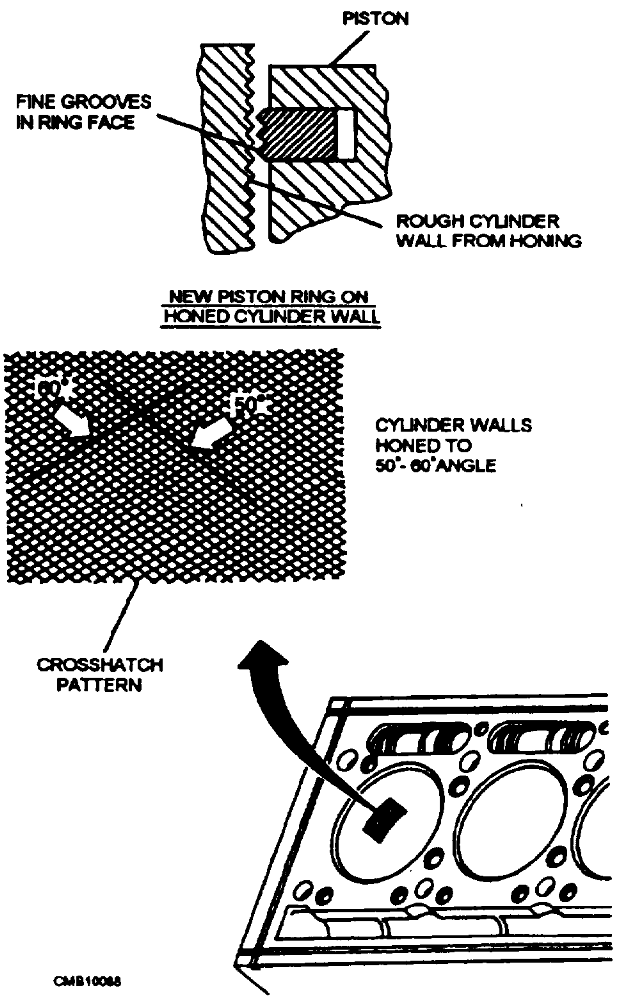


Figure 3-37.—Piston ring wear-in.

When piston rings are new, a period of running is necessary to wear the piston rings a small amount, so they conform perfectly to the cylinder walls. The cylinder walls are surfaced with a tool called a hone, which leaves fine scratches in the cylinder walls (fig. 3-37). The piston rings are made with grooves in their faces, which rub against the roughened cylinder walls, serving to accelerate ring wear during the initial stages. As the surfaces wear smooth, the rings wear in.

Extreme pressure may be applied to high spots on the piston rings during the wear-in period. This can cause the piston rings to overheat at these points and cause damage to the cylinder walls in the form of rough streaks. This condition is called **scuffing.** New piston rings are coated with a porous material, such as graphite, phosphate, or molybdenum. These materials absorb oil and serve to minimize scuffing. As the rings wear in, the coatings wear off.

Some piston rings are chrome-plated. Chrome-plated rings provide better overall wearing qualities. They also are finished to a greater degree of accuracy, which lets the piston rings wear in faster.

Connecting Rods

Connecting rods connect the pistons to the crankshaft. They must be strong enough to transmit the thrust of the pistons to the crankshaft and to withstand the internal forces of the directional changes of the pistons. The connecting rods (fig. 3-38) are in the form of an I-beam. This design gives the highest overall strength and lowest weight. They are made of forged

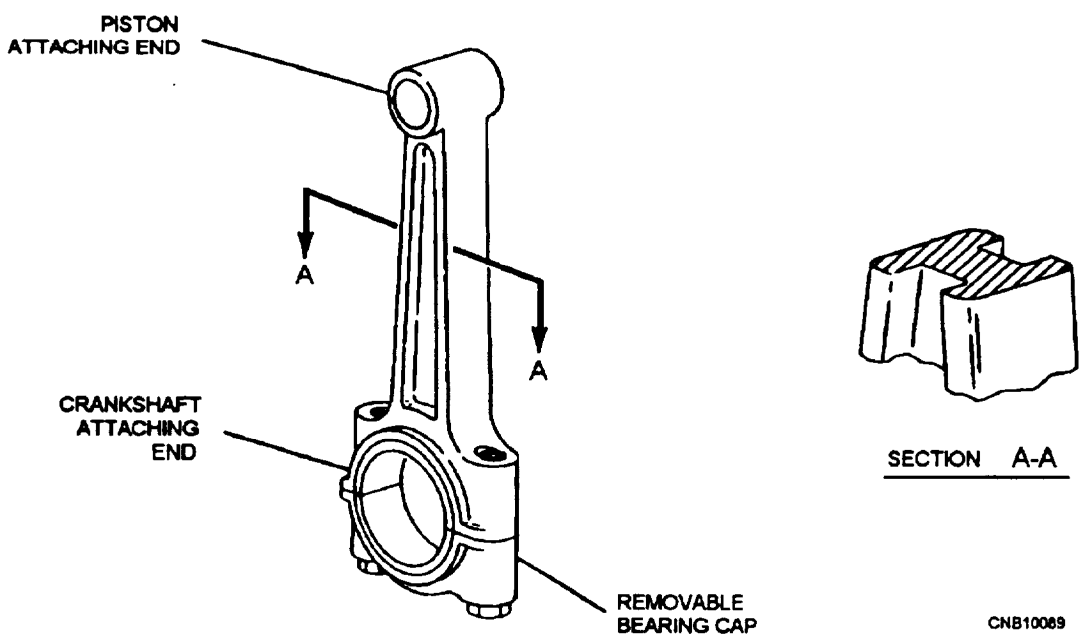


Figure 3-38.—Connecting rod construction.

steel but may also be made of aluminum in smaller engines.

The upper end of the connecting rod is connected to the piston by the piston pin. The piston pin is locked in the pin bosses, or it floats in both piston and connecting rod. The upper hole of the connecting rod has a solid bearing (bushing) of bronze or similar material. As the lower end of the connecting rod revolves with the crankshaft, the upper end is forced to turn back and forth on the piston pin. Although the movement is slight, the bushing is necessary because the temperatures and pressures are high. If the piston pin is semifloating, a bushing is not needed.

The lower hole in the connecting rod is split, so it can be clamped around the crankshaft. The bottom part, or cap, is made of the same type of material as the rod and is attached by two or more bolts. The surface that bears on the crankshaft is generally a bearing material in the form of a split shell, although, in a few cases, it may be spun or die-cast in the inside of the rod and cap during manufacture. The two parts of the separate bearing are positioned in the rod and cap by dowel pins and projections or by a short brass screw. The shell may be of Babbitt metal that is die-cast on a backing of bronze or steel. Split bearings may be of the precision or semiprecision type.

The **PRECISION** type of bearing is accurately finished to fit the crankpin and does not require further fitting during installation. It is positioned by projections on the shell that match relief in the rod and cap. The projections prevent the bearings from moving sideways and from rotary motion in the rod and cap.

The **SEMIPRECISION** type of bearing is fastened to or die-cast with the rod and cap. Before installation, it is machined and fitted to the proper inside diameter with the cap and rod bolted together.

The connecting rod bearings are fed a constant supply of oil through a hole in the crankshaft journal. A hole in the upper bearing half feeds a passage in the connecting rod to provide oil to the piston pin.

Connecting rod numbers are used to assure a proper location of each connecting rod in the engine. They all assure that the rod cap is installed on the rod body correctly. When connecting rod caps are being manufactured, they are bolted to the connecting rods. Then the lower end holes are machined in the rods. Since the holes may not be perfectly centered, rod caps must **NOT** be mixed up or turned around. If the cap is installed without the rod numbers in alignment, the bore will **NOT** be perfectly round. Connecting rod caps, crankshaft, and bearing damage will result.

In addition to the proper fit of the connecting rod bearings and the proper position of the connecting rod, the alignment of the rod itself must be considered. That is to say, the hole for the piston pin and the crankpin must be precisely parallel. Equipment of suitable accuracy is available for checking connecting rods (fig. 3-39). **EVERY** connecting rod should be checked for proper alignment just before it is installed in the engine. Misalignment of connecting rods causes many hard to locate noises in the engine.

Crankshaft

As the pistons collectively might be regarded as the heart of the engine, so the **CRANKSHAFT** (fig. 3-40) may be considered its backbone. The crankshaft is the part of the engine that transforms the reciprocating motion of the piston to rotary motion. It transmits power through the flywheel, the clutch, the transmission, and the differential to drive your vehicle.

Crankshafts are made from forged or cast steel. Forged steel is the stronger of the two and is used in commercial and military engines. The cast unit is primarily used in light- and regular-duty gasoline engines. After the rough forging or casting is produced, it becomes a finished product by going through the following steps:

- Each surface is rough machined
- Each hole is located and drilled.

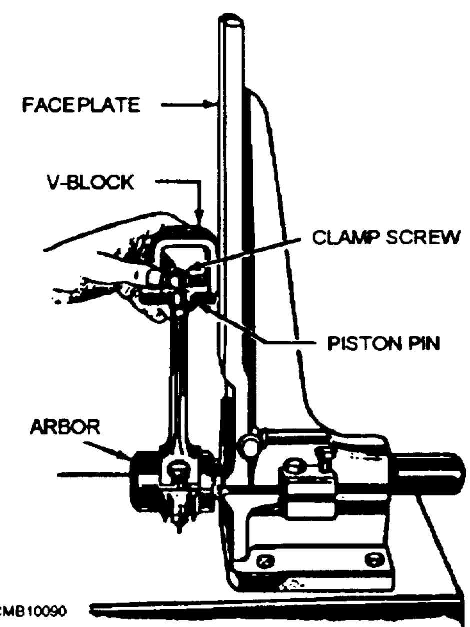


Figure 3-39.—Checking connecting rod alignment.

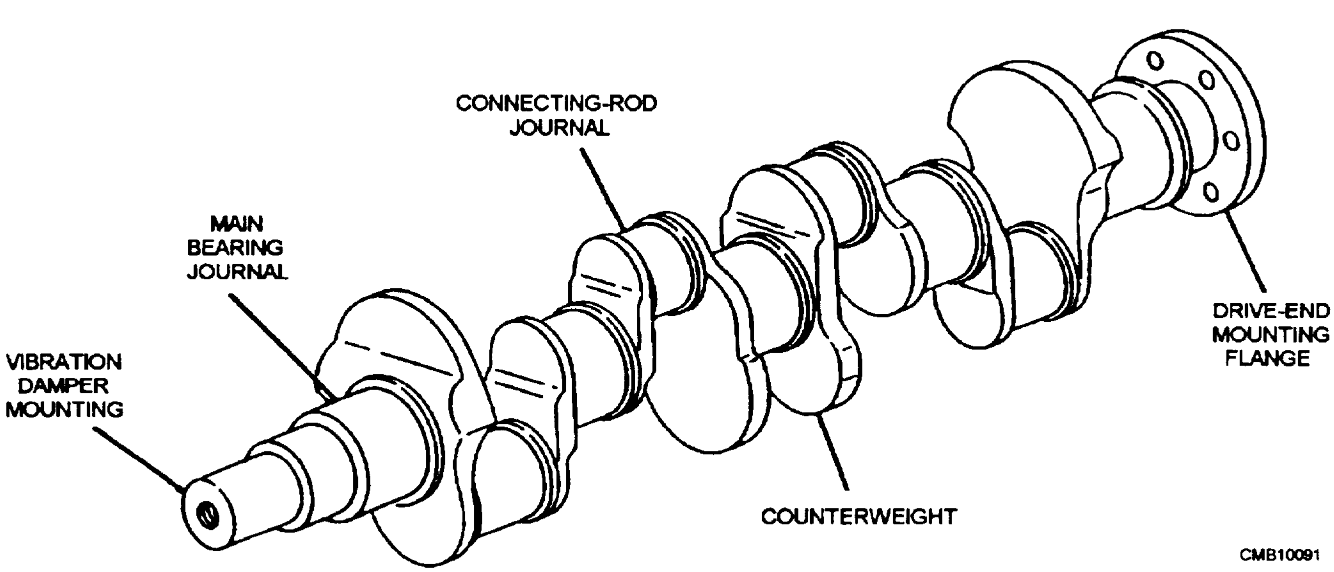


Figure 3-40.—Crankshaft construction.

- The crankshaft, with the exception of the bearing journals, is plated with alight coating of copper.
- The bearing journals are case-hardened.
- The bearing journals are ground to size.
- Threads are cut into necessary bolt holes.

Crank throw arrangements for four-, six-, and eight-cylinder engines are shown in figure 3-41. The arrangements of throws determine the firing order of the engine. The position of the throws for each cylinder arrangement is paramount to the overall smoothness of operation. For the various engine configurations, typical throws are arranged as follows:

- In-line four-cylinder engines have throws one and four offset 180 degrees from throws two and three.
- V-type engines have two cylinders operating off each throw. The two end throws are on one plane offset 180 degrees apart. The two center throws are on another common plane, which is also 180 degrees apart. The two planes are offset 90 degrees from each other.
- In-line six-cylinder engines have throws a-ranged on three planes. There are two throws on each plane that are in line with each other. The three planes are arranged 120 degrees apart.
- V-type twelve-cylinder engines have throw arrangements like the in-line six-cylinder engine. The difference is that each throw accepts two-engine cylinders.
- V-type six-cylinder engines have three throws at 120- degree intervals. Each throw accepts two-engine cylinders.

The crankshaft is supported in the crankcase and rotates in the main bearings (fig. 3-42). The connecting rods are supported on the crankshaft by the rod bearings. Crankshaft bearings are made as precision inserts that consist of a hard shell of steel or bronze with a thin lining of antifrictional metal or bearing alloy. Bearings must be able to support the crankshaft rotation and deliver power stroke thrust under the most adverse conditions.

The crankshaft rotates in the **MAIN BEARINGS** located at both ends of the crankshaft and at certain intermediate points. The upper halves of the bearing fit right into the crankcase and the lower halves fit into the caps that hold the crankshaft in place (fig. 3-43). These bearings often are channeled for oil distribution and may be lubricated with crankcase oil by pressure through drilled passages or by splash. Some main bearings have an integral thrust face that eliminates crankshaft end play. To prevent the loss of oil, place the seals at both ends of the crankshaft where it extends through the crankcase. When main bearings are replaced, tighten the bearing cap to the proper tension with a torque wrench and lock them in place with a cotter pin or safety wire after they are in place.

VIBRATION DUE TO IMBALANCE is an inherent problem with a crankshaft that is made with

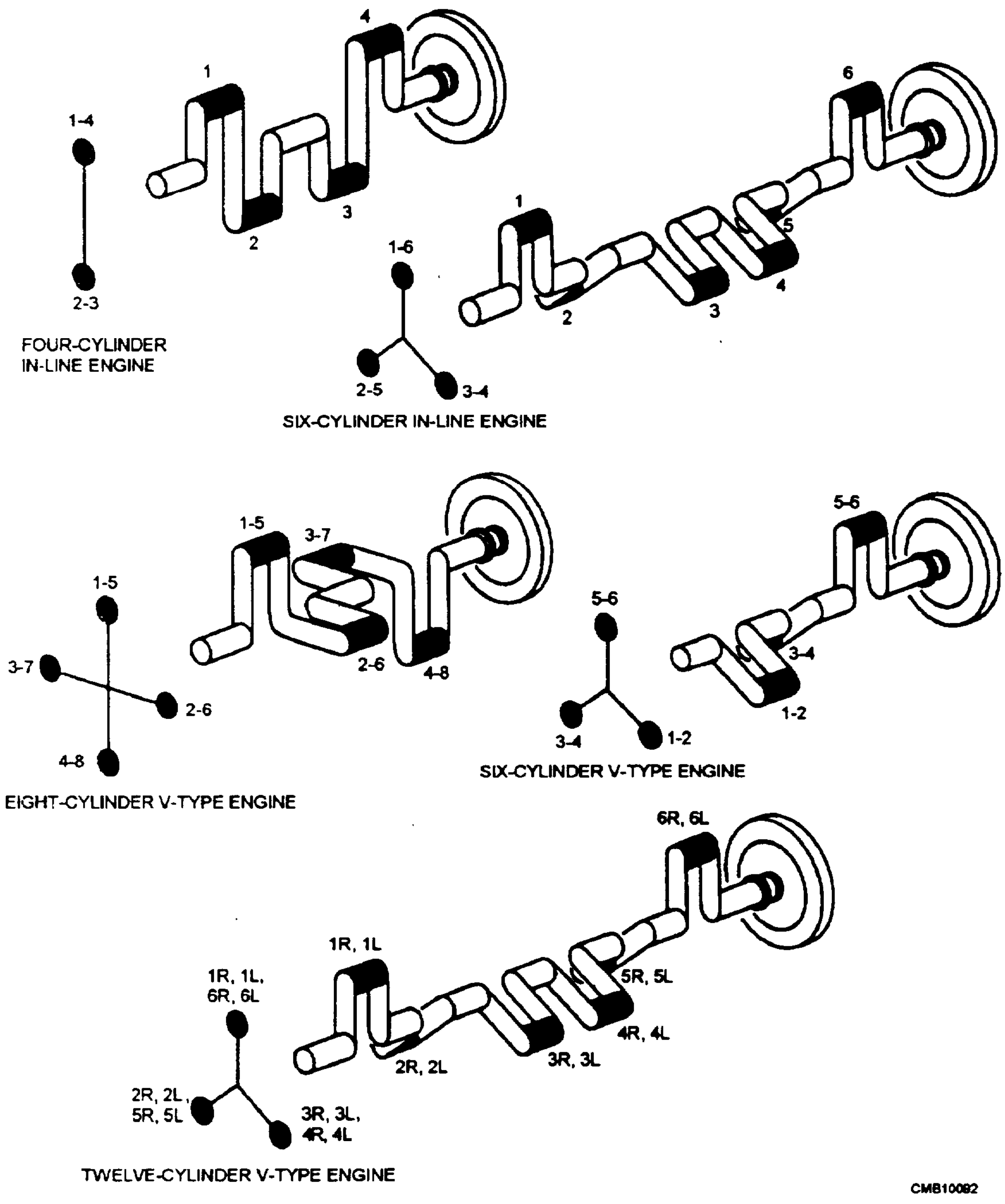


Figure 3-41.—Crankshaft throw arrangements.

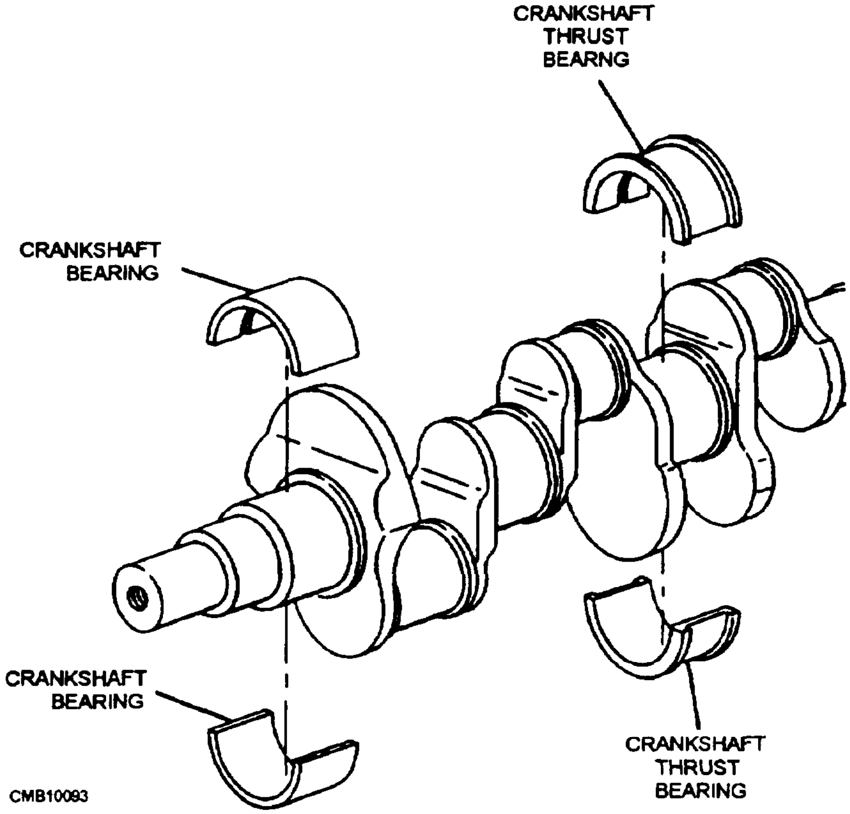


Figure 3-42.—Crankshaft bearings.

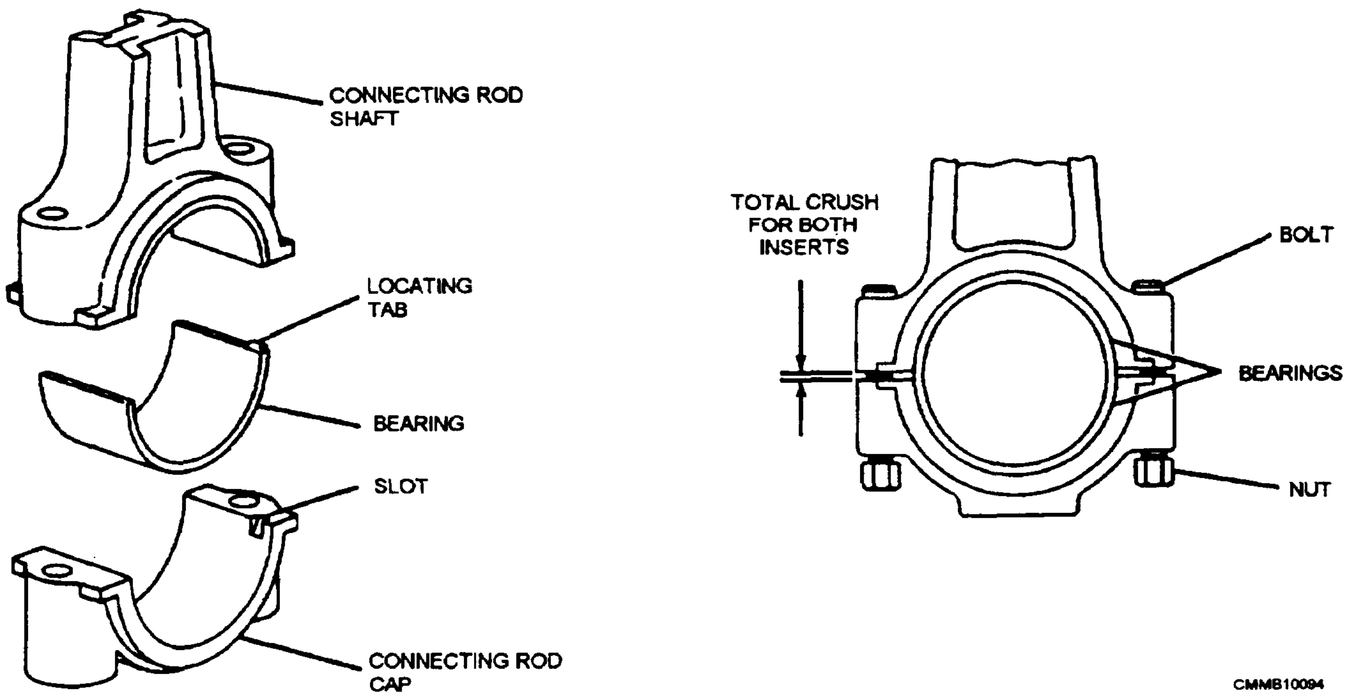


Figure 3-43.—Typical insert bearing installation.

offset throws. The weight of the throws tend to make the crankshaft rotate elliptically. This is aggravated further by the weight of the piston and the connecting rod. To eliminate the problem, position the weights along the crankshaft. One weight is placed 180 degrees away from each throw. They are called counterweights and are usually part of the crankshaft but may be a separate bolt on items on small engines.

The crankshaft has a tendency to bend slightly when subjected to tremendous thrust from the piston. This deflection of the rotating member causes vibration. This **VIBRATION DUE TO DEFLECTION** is minimized by heavy crankshaft construction and sufficient support along its length by bearings.

TORSIONAL VIBRATION occurs when the crankshaft twists because of the power stroke thrusts. It is caused by the cylinders furthest away from the crankshaft output. As these cylinders apply thrust to the crankshaft, it twists and the thrust decreases. The twisting and unwinding of the crankshaft produces a vibration. The use of a vibration damper at the end of the crankshaft opposite the output acts to absorb torsional vibration.

Vibration Damper

The power impulses of an engine tend to set up torsional vibration in the crankshaft. If this torsional vibration were not controlled, the crankshaft might actually break at certain speeds; a vibration damper mounted on the front of the crankshaft controls this vibration.

There are a few variations of the vibration damper (fig. 3-44), but they all accomplish their task basically in

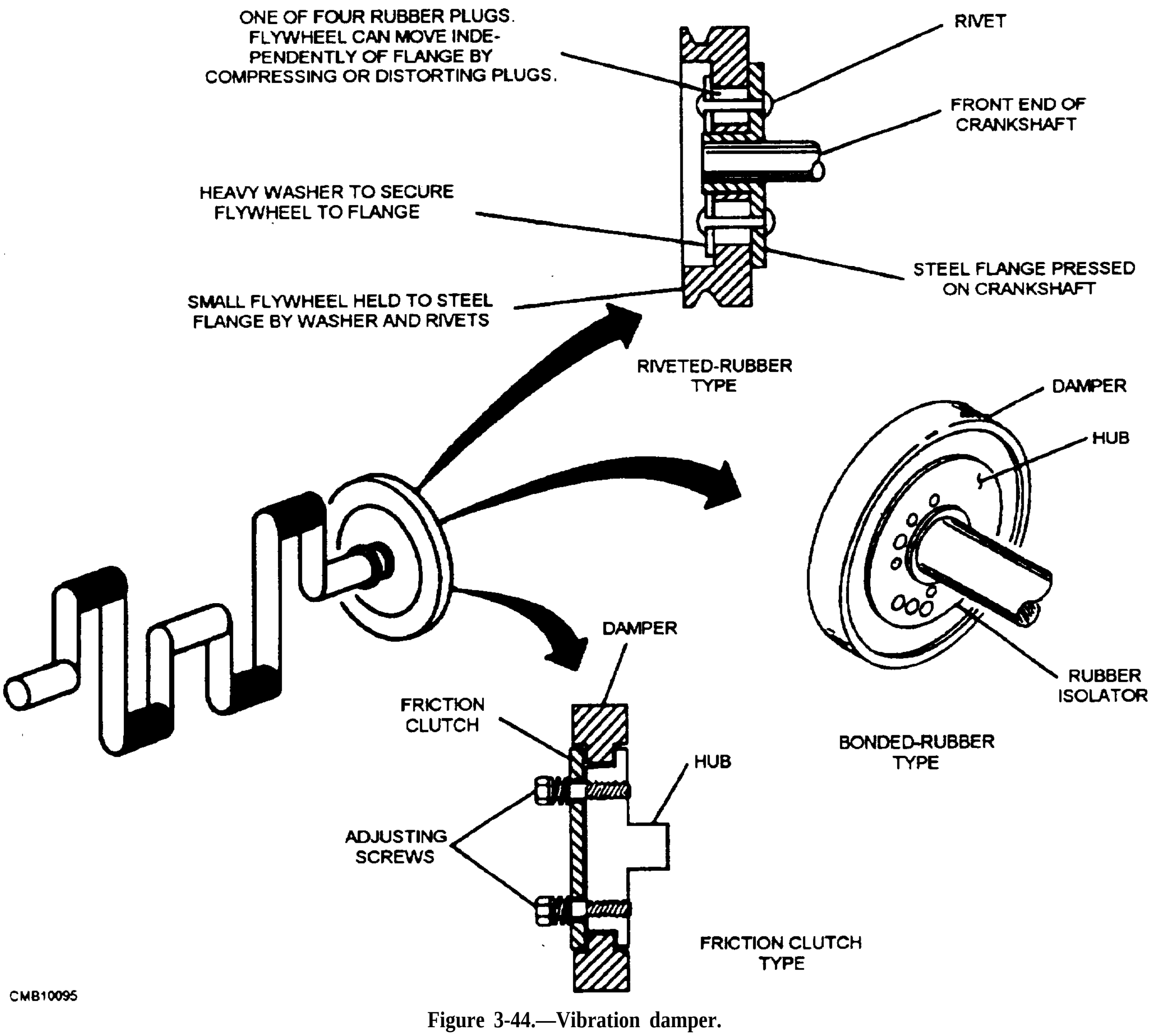


Figure 3-44.—Vibration damper.

the same manner. They all use a two-piece design The differences in design are in how the two pieces are linked together. One type of damper links the pieces together by an adjustable friction clutch. Whenever a suddenchange in crankshaft speed occurs, it causes the friction clutch to slip. This is because the outer section of the damper tends to continue at the same speed. The slippage of the clutch acts to absorb the torsional vibration. Another type of damper links the two pieces together with rubber. As the crankshaft speeds up, the rubber compresses, storing energy. This minimizes the effect of crankshaft speed increase. As the crankshaft unwinds, the damper releases energy stored in the compressed rubber to cushion the speed change in the other direction.

Flywheel

The flywheel (fig. 3-45) stores energy from the power strokes and smoothly delivers it to the drive train of the vehicle between the engine and the transmission. It releases this energy between power impulses, assuring fewer fluctuations in speed and smoother engine operation. The flywheel is mounted at the rear of the crankshaft near the rear main bearing. This is usually the longest and heaviest main bearing in the engine, as it must support the weight of the flywheel.

The flywheel on large, low-speed engines is usually made of cast iron. This is desirable because the heavy weight of the cast iron helps the engine maintain a steady speed. Small, high-speed engines usually use a forged steel or forged aluminum flywheel for the following reasons:

- The cast iron is too heavy, giving it too much inertia for speed variations necessary on small engines.
- Cast iron, because of its weight, pulls itself apart at high speeds due to centrifugal force.

When equipped with a manual transmission, the flywheel serves to mount the clutch With a vehicle that is equipped with an automatic transmission, the flywheel supports the front of the torque converter. In some configurations, the flywheel is combined with the torque converter. The outer edge of the flywheel carries the ring gear, either integral with the flywheel or shrunk on. The ring gear is used to engage the drive gear on the starter motor for cranking the engine.

VALVE AND VALVE MECHANISMS

There are two valves for each cylinder in most engines—one intake and one exhaust. Since these valves operate at different times, it is necessary that a separate operating mechanism be provided for each valve. Valves are held closed by heavy springs and by compression in the combustion chamber. The purpose of the valve actuating mechanism is to overcome spring pressure and open the valve at the proper time. The valve actuating mechanism includes the engine camshaft, the camshaft followers (tappets), the pushrods, and the rocker arms.

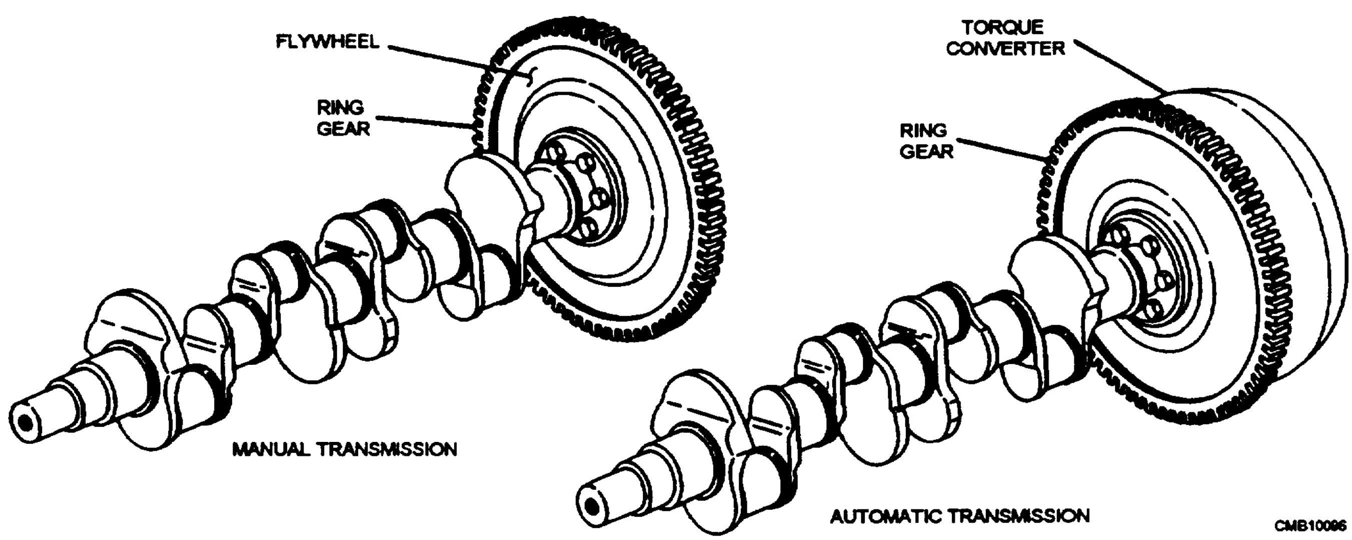


Figure 3-45.—Flywheel.

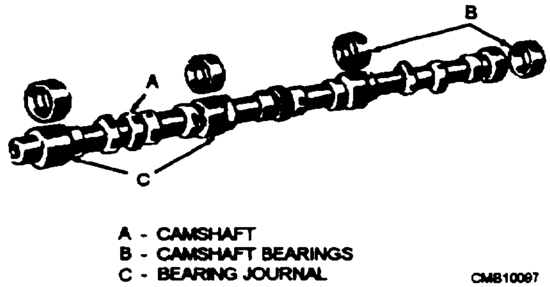


Figure 3-46.—Camshaft and bushings.

Camshaft

The camshaft provides for the opening and closing of the engine valves. The camshaft (fig. 3-46) is enclosed in the engine block. It has eccentric lobes (cams) ground on it for each valve in the engine. As the camshaft rotates, the cam lobe moves up under the valve tappet, exerting an upward thrust through the tappet against the valve stem or the pushrod. This thrust overcomes the valve spring pressure as well as the gas pressure in the cylinder, causing the valve to open. When the lobe moves from under the tappet, the valve spring pressure reseats the valve.

On L-, F-, or I-head engines, the camshaft is located to one side and above the crankshaft, while in V-type engines, it is located directly above the crankshaft On the overhead camshaft engine, the camshaft is located above the cylinder head

The camshaft of a four-stroke-cycle engine turns at one half of engine speed. It is driven off the crankshaft through timing gears or a timing chain. (The system of camshaft drive is dismissed later in this chapter.) In a two-stroke-cycle engine, the camshaft must turn at the same speed as the crankshaft, so each valve opens and closes once in each revolution of the engine.

In most cases, the camshaft does more than operate the valve mechanism. It may have external cams or gears that operate the fuel pumps, the fuel injectors, the ignition distributor, or the lubrication pump.

Camshafts are supported in the engine block by journals in bearings. Camshaft bearing journals are the largest machined surfaces on the shaft. The bearings are made of bronze and are bushings, rather than split bearings. The bushings are lubricated by oil circulating through drilled passages from the crankcase. The stresses on the camshaft are small; therefore, the bushings are not adjustable and require little attention. The camshaft bushings are replaced only when the engine requires a complete overhaul.

Followers

Camshaft followers are part of the valve actuating mechanism that contacts the camshaft. You will hear them called valve tappets or valve lifters. The bottom surface is hardened and machined to be compatible with the surface of the camshaft lobe. There are two basic type of followers—mechanical and hydraulic.

MECHANICAL (or solid) tappets (fig. 3-47) are simply barrel-shaped pieces of metal. When used in flathead engines, they have an adjusting screw mechanism to set the clearance between the tappets and the valve stems. Mechanical tappets may also come with a wider bottom surface. These are called

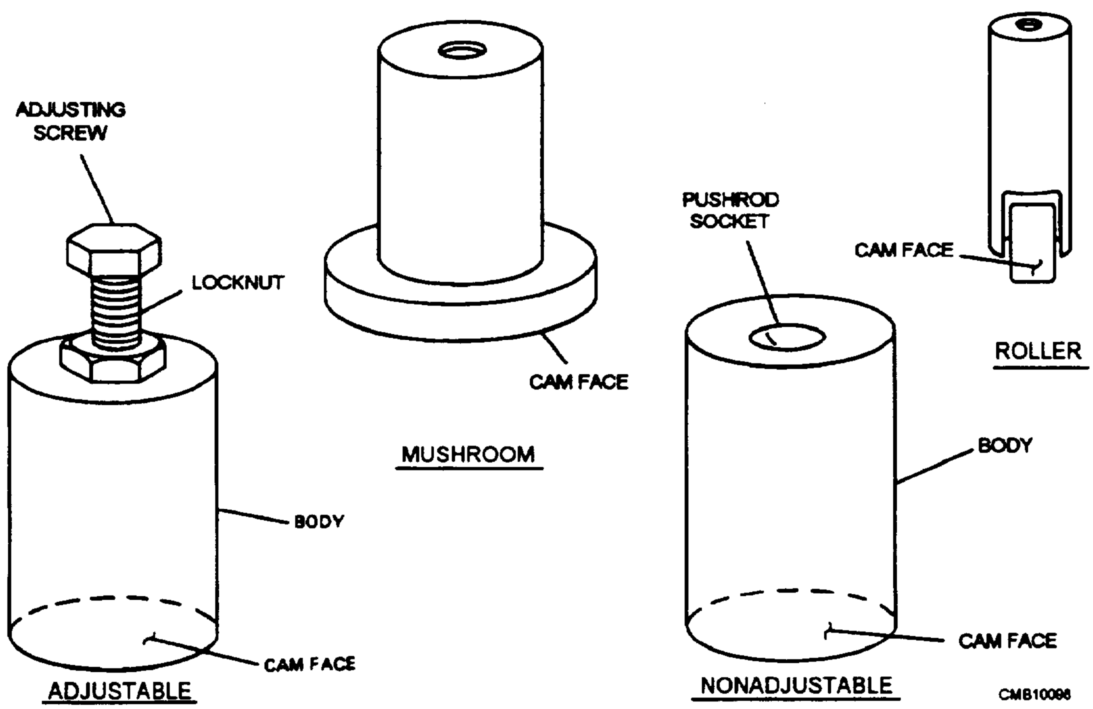


Figure 3-47.—Mechanical tappets

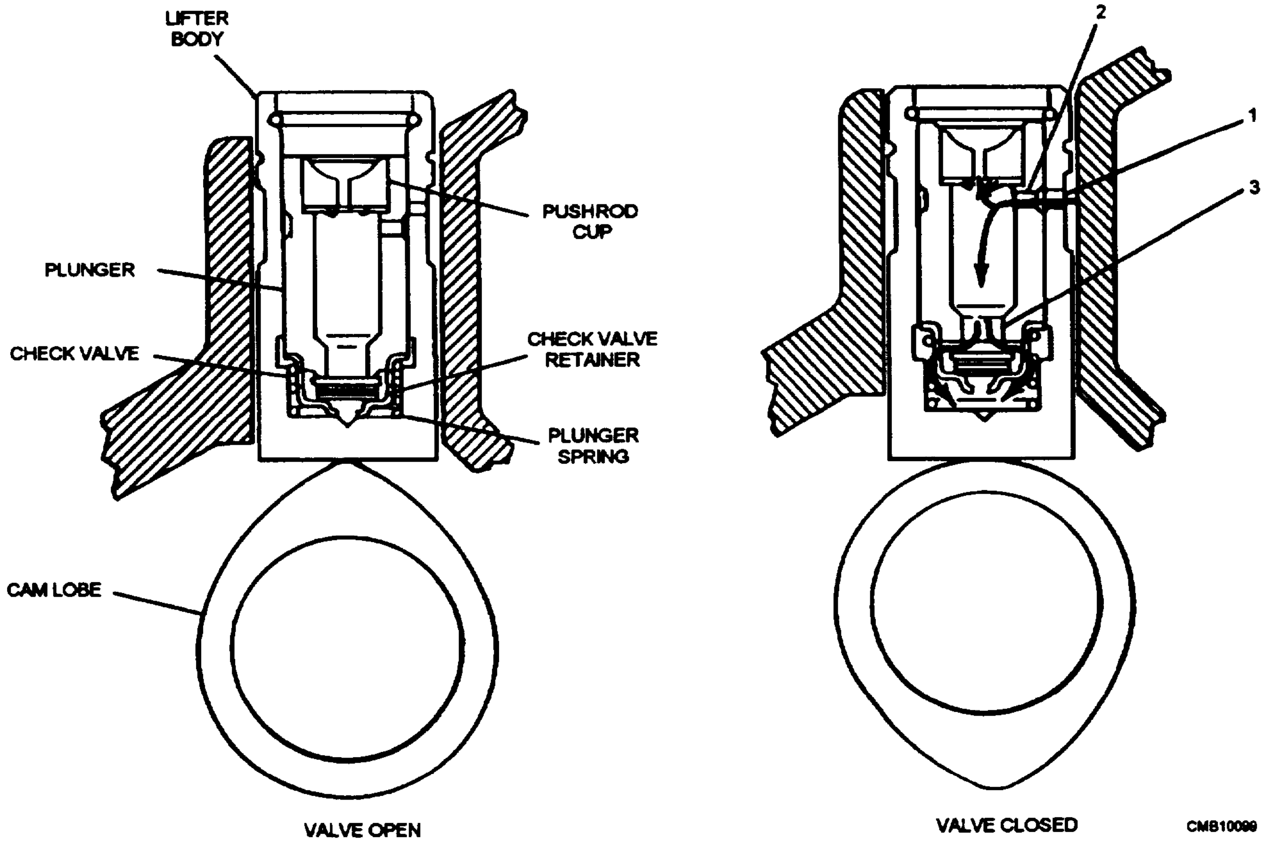


Figure 3-48.—Hydraulic tappets.

mushroom tappets. Another variation is the roller tappet. It has a roller contacting the camshaft and is used mostly in heavy-duty applications.

HYDRAULIC tappets are very popular in overhead valve engines. They use oil under pressure to maintain zero clearance in the valve mechanism automatically. The lifter body, which contacts the camshaft lobe, is hollow. Inside the lifter body, there is a plunger that operates the valve mechanism. Injecting oil into the cavity under the plunger regulates its height, thereby adjusting valve mechanism clearance. The hydraulic lifter operates as follows (fig. 3-48): oil, supplied by the engine lubrication system, reaches the lifter body and enters it through passage (1). The oil then passes through passage (2) to fill the plunger. The oil then passes through passage (3) where it pushes the check valve off its seat to enter the cavity under the plunger. As oil fills the cavity, it pushes the plunger up to where it contacts the valve mechanism. When the camshaft pushes the lifter body up, the oil is trapped in the cavity and cannot escape because the check ball seals the opening. This trapped oil then becomes a solid link between the lifter body and the plunger. The constant pressurized supply of oil will maintain zero clearance in the valve mechanism.

The face of the tappet and the lobe of the camshaft are designed so the tappet rotates during operation (fig. 3-49). The cam lobe is machined with a slight taper that

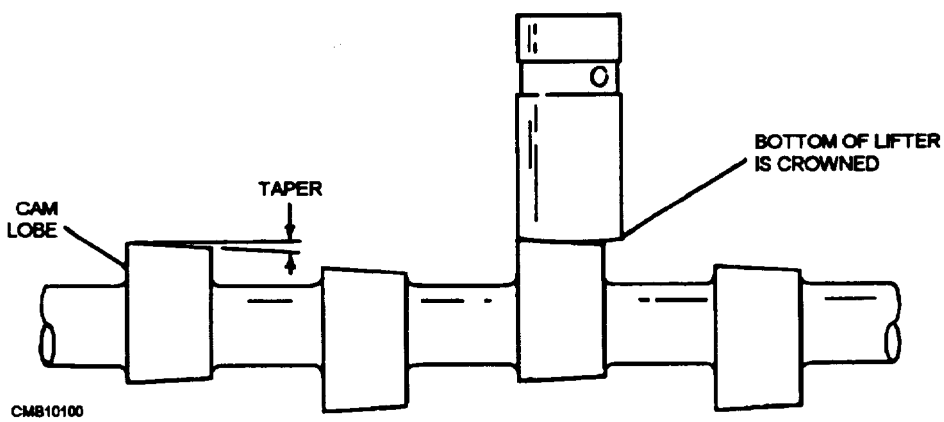


Figure 3-49.—Tappet-to-can lobe relationship.

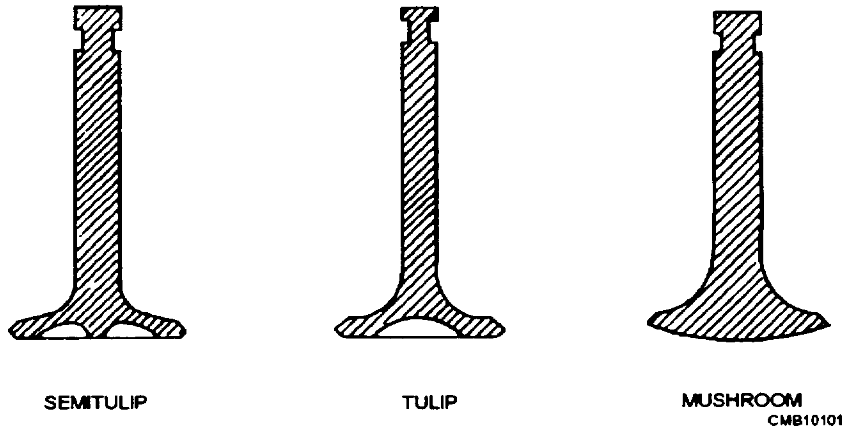


Figure 3-50.—Valve shapes.

mates with a crowned tappet face. The camshaft lobe does not meet the tappet in the center of its face. The design causes the tappet face to rotate on the cam lobe, rather than slide. This greatly increases component life.

Valve and Valve Seats

Each cylinder in a four-stroke-cycle engine must have one intake and one exhaust valve. The valves that are commonly used are of the poppet design. The word *poppet* is derived from the popping action of the valve. Poppet-type valves are made in the following three basic shapes: **semitulip, tulip,** and **mushroom** (fig. 3-50). The valve shape used in a given engine depends on requirements and shape of the combustion chamber.

Construction and design considerations are very different for intake and exhaust valves. The difference is based on their temperature operating ranges. Intake valves are kept cool by the incoming intake mixture. Exhaust valves are subject to intense heat from the burnt gases that pass by it. The temperature of an exhaust valve can be in excess of 1300°F. Intake valves are made of **nickel chromium alloy.** Whereas, exhaust valves are made from **silichrome alloy.** In certain heavy-duty and most air-cooled engines, the exhaust valves are **sodium filled.** During engine operation, the sodium inside the hollow valve melts. When the valve opens, the sodium splashes down into the valve head and collects heat. Then, when the valve closes, the sodium splashes up into the valve stem. Heat transfers out of the sodium, into the stem, valve guide, andengine coolant. In this way, the valve is cooled. Sodium-filled valves are light and allow high engine rpm for prolonged periods.

In vehicles that use unleaded fuel, a **stellite valve** is preferred. A stellite valve has a special hard metal coating on its face. Lead additives in gasoline, other than increasing octane, act as a lubricant. The lead coats the valve face and seat to reduce wear. With unleaded fuel, the wear of the valve seat and valve face is accelerated. To prevent this and prolong valve service life, use a stellite valve.

Valve seats are important, as they must match the face of the valve head to form a perfect seal. The seats are made so they are concentric with the valve guides; that is, the surface of the seat is an equal distance from the center of the guide all around Although some earlier engines were designed with flat contact surface for the valve and valve seat, most are now designed with valve seat angles of 30 to 45 degrees, as shown in figure 3-51. This angle helps prevent excessive accumulation

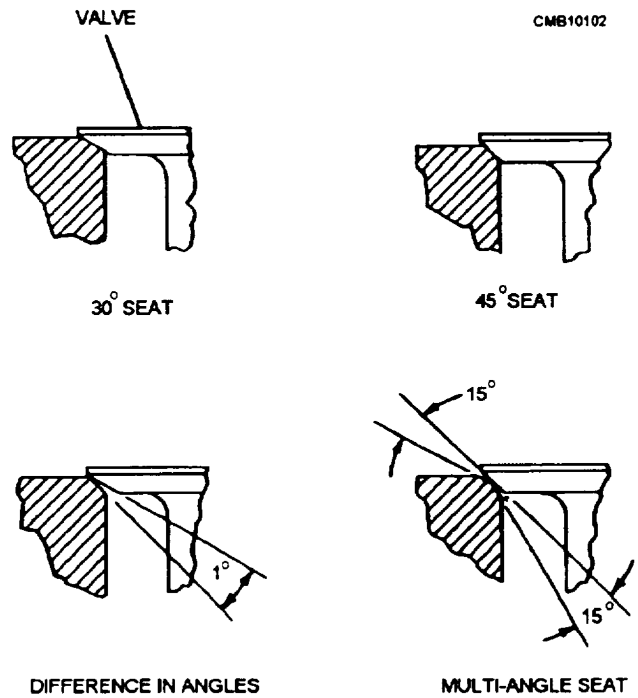


Figure 3-51.—Valve-to-valve seat relationship.

of carbon on the contact surface of the seat—a condition that keeps the valve from closing properly. To further reduce carbon build up, there is an interference angle (usually 1 degree) between the valve and seat. In some cases, a small portion of the valve seat has an additional 15-degree angle ground into it to narrow the contact area of the valve face and seat. When you reduce the contact area, the pressure between the mating parts is increased, thereby forming a better seal.

The valve seats may be an integral part of the cylinder head or an insert pressed into the cylinder head. Valve seat inserts are commonly used in aluminum cylinder heads. Steel inserts are needed to withstand the extreme heat. When a valve seat insert is badly worn from grinding or pitting, it must be replaced.

Valve Guides

The valve guides are the parts that support the valves in the cylinder head. They are machined to fit a few thousandths of an inch clearance with a valve stem, This close clearance is important for the following reasons:

- It keeps lubricating oil from getting sucked into the combustion chamber past the intake valve stem during the intake stroke.
- It keeps exhaust gases from getting into the crankcase area past the exhaust valve stem during the exhaust stroke.
- It keeps the valve face in perfect alignment with the valve seat.

Valve guides may be cast integrally with the head, or they may be removable (fig. 3-52). Removable guides are press-fit into the cylinder head.

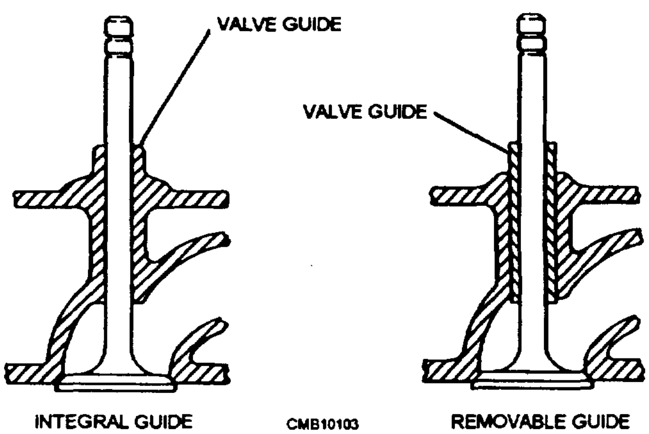


Figure 3-52.—Valve guides.

Valve Springs, Retainers, Seals, and Valve Rotators

The valve assembly is completed by the spring, the retainer, the seal, and the valve rotator (fig. 3-53). The spring, which keeps the valve in a normally closed position, is basically the same for all engines; however, the number and types of coils can vary. Most valves have only one spring, but, in some cases, there may be two—an inner spring and an outer spring. The second spring increases the pressure holding the valve closed. Low-spring tension can cause **valve float** (spring too weak to close the valve at high rpm).

A valve retainer and keepers lock the valve spring on the valve. The retainer is a specially shaped washer that fits over the top of the valve spring. The keepers, or locks, fit into the valve stem grooves, holding the retainer and spring in place.

The seal keeps the valve operating mechanism oil from running down the valve stem and into the combustion chamber. Valve seals come in two basic types—umbrella and O ring. Both are common on modern engines. The umbrella valve seal is shaped like a cup and can be made of neoprene plastic or rubber. An umbrella valve seal slides down over the valve stem before the spring and retainer. It covers the small

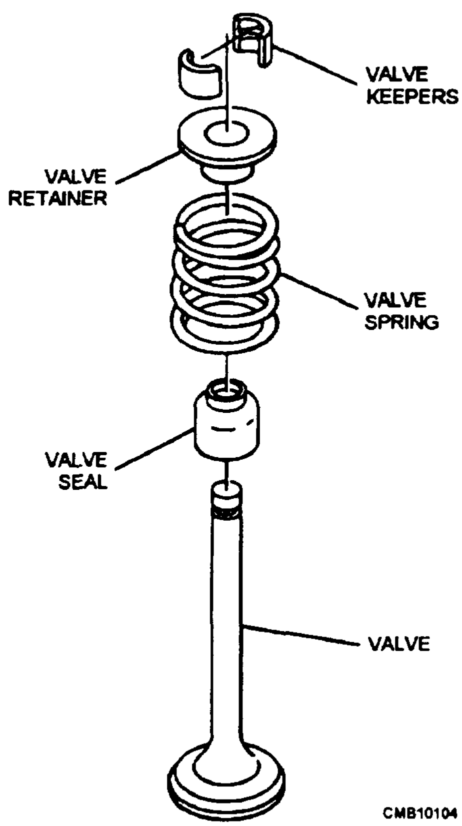


Figure 3-53.—Valve spring, retainer, and seal.

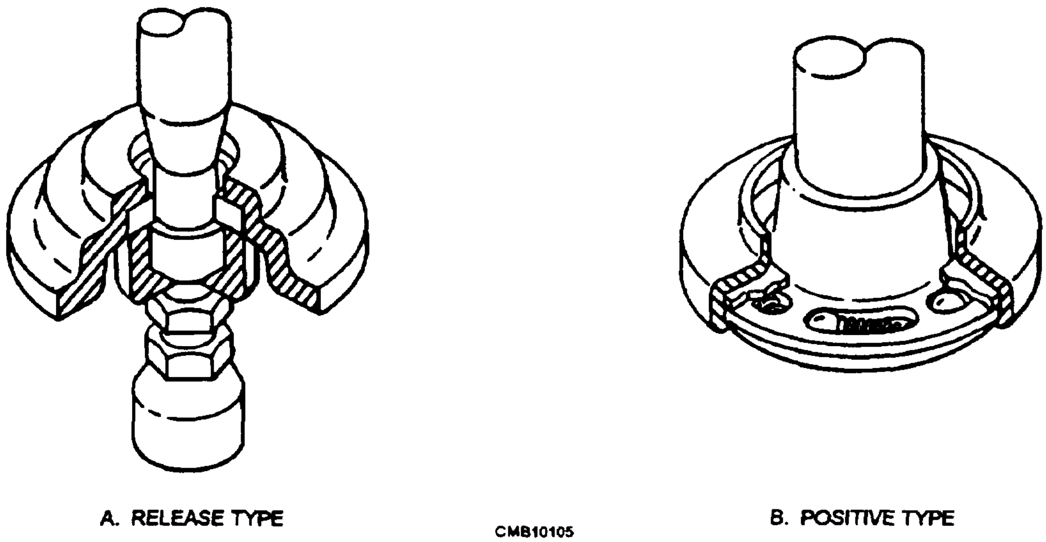


Figure 3-54.—Valve rotators.

clearance between the valve stem and guide. The O ring is a small, round seal that fits into an extra groove cut into the valve stem. It fits on the valve stem after the spring and retainer. Unlike the umbrella type, it seals the gap between the retainer and the valve stem, not the guide and stem. It stops oil from flowing through the retainer down the stem and into the guide.

A valve rotator (fig. 3-54) turns the valve to prevent a carbon buildup and hot spots on the valve face. There are two types of retainers—the release type and the positive type. The release type of rotator releases the spring tension from the valve while open; this allows the valve to rotate from engine vibration The positive rotator is a two-piece valve retainer with a flexible washer between the two pieces. A series of balls between the retainer pieces roll on machined ramps, as pressure is applied and released from the opening and closing of the valve. The movement of the balls up and down the ramps translates into rotations of the valve.

Reconditioning Valves

Valve reconditioning includes grinding valves and valve seats, adjusting valve tappet clearances, installing new valve seat inserts, and timing the valves. Together, these operations constitute the **VALVE SERVICE** necessary for smooth engine performance and maximum power output.

To recondition valves and valve seats, first remove the cylinder head from the engine. Once the cylinder head is off, remove the carbon from the head, the cylinder block, and the pistons. In cleaning the top of the piston, you must exercise care to prevent gouging and scratching, as rough spots collect carbon readily and lead to preignition and detonation during operation. Remove the valves using a valve spring compressor. Next, clean the valves with a wire brush or buffing wheel (fig. 3-55). When the buffing wheel is being used, make sure you wear proper eye protection to prevent wire and other foreign matter from flying into your eyes.

Be careful not to interchange the valves. Bach valve must be replaced in the same valve port from which it was removed. The valve stem moving up and down in the valve guide develops a wear pattern. And, if the valves are interchanged, a new wear pattern is developed. This causes excessive wear on the valve stem and guide.

To eliminate confusion, you should devise a system to identify a valve with the cylinder from which it was taken. The most common way to identify valves is to

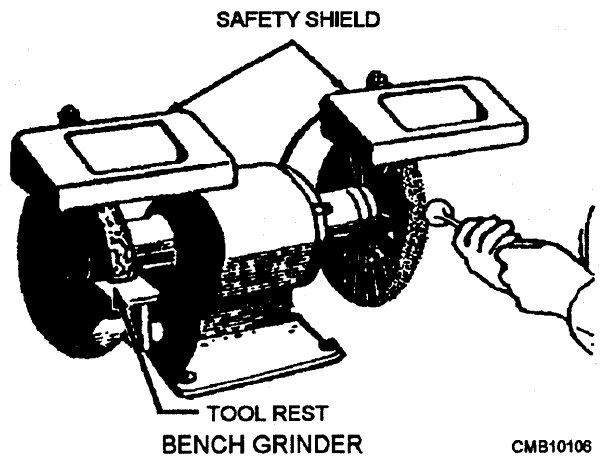


Figure 3-55.—Cleaning a valve with a wire buffing wheel.

place them on a piece of board with holes drilled and numbered to correspond with the cylinder each valve came from.

The next step is to resurface the valve face. This is done by using a valve grinding or refacing machine. **VALVE GRINDING** is done by machining a fresh, smooth surface on the face and stem tips. Valve faces suffer from burning, pitting, and wear caused by opening and closing millions of times during the service life of the engine. Valve stem tips wear because of friction from the rocker arms.

Although there are some variations in design, most valve grinding machines (fig. 3-56) are basically the same. They use a grinding stone and a precision chuck to remove a thin layer of metal from the valve and stem tip. The following steps are used in preparing to reface a valve:

- **DRESS THE STONE** by using a diamond cutter to true stone surface (fig. 3-57). Do this before grinding the valves. A diamond-tipped cutting attachment is provided with the machine for truing the stone. Follow the equipment manufacturer's instructions for that specific piece equipment.

CAUTION

Be careful when using a diamond tool to dress a stone. Wear eye protection and feed the diamond into the stone **SLOWLY.** If fed too fast, tool or stone breakage may result.

- **SET THE CHUCK ANGLE** by rotating the valve grinding machine chuck assembly. An **interference angle** (normally 1 degree difference in valve face angle and valve seat angle) is set on the machine. If the valve seat is

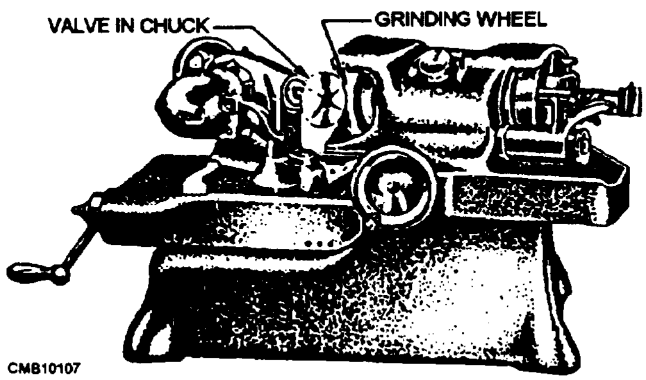


Figure 3-56.—Valve-refacing machine.

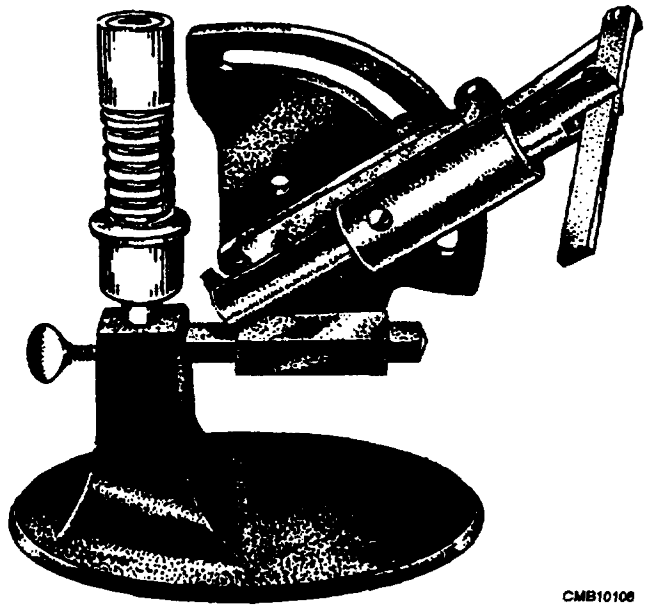


Figure 3-57.—Stone dresser.

45 degrees, the chuck is set to 44 degrees. This allows for reduced break-in and sealing time.

- **CHUCK THE VALVE** in the valve grinding machine by inserting the valve stem into the chuck Make sure the stem is inserted so the chuck grasps the machine surface nearest the valve head.

WARNING

The chuck must **NOT** clamp onto an unmachined surface or runout will occur.

Before grinding, inspect each valve face for burning and each stem for wear. Replace valves that are badly worn or burned. Grind a new valve along with the old, used valves.

WARNING

Wear a face shield when grinding valves. The stone could shatter, throwing debris into your face.

To grind the valve face, turn on the machine and cooling fluid **SLOWLY** feed the valve into the stone. While feeding, slowly move the valve back and forth in front of the stone. Use the full face of the stone but do **NOT** let the valve face move out of contact with the stone while cutting. Grind the valve only long enough to clean up its face. When the full valve face looks shiny with no darken pits, shut the machine off and inspect the face.

Grinding, by removing metal from the face, makes the valve stem extend through the head more. This affects spring tension and rocker-arm geometry. Grind the face of the valve as little as possible. A **sharp valve margin** (fig. 3-58) indicates excessive valve face removal and requires valve replacement. If the margin is too thin, the valve can burn when returned to service. It may not be thick enough to dissipate heat fast enough. The head of the valve can actually begin to melt, burn, and blow out the exhaust port. Refer to the manufacturer's manual for specifications about minimum valve margin of thickness.

If the head of the valve wobbles as it turns on the valve grinding machine, the valve is either bent or chucked improperly. Turn off the machine and check for causes. If the valve is bent, replace it with a new one.

If a burned valve is not noticed during initial inspection, it will show up when excess grinding is required to clean up the valve face. A normal amount of grinding does not remove a deep pit or groove. Replace the valve if it is burned.

Another area on the valve that must be attended to is the valve stem. This is due to wear from the valve operating mechanisms. When the tip end of the valve stems is rough, smooth them by grinding lightly with a special attachment furnished with the valve grinding machine. Grind as little off the stem as possible. Many stems are hardened and too much grinding results in rapid wear when the valve is returned to service. Generally, cut the same amount of metal off the face and stem. This helps to keep the valve train geometry correct.

Valve Guide Service

Servicing of valve guides is an important, but often neglected, part of a good valve job. The guide must be clean and in good condition before a good valve seat can be made. Valve guide wear is a common problem; it allows the valve to move sideways in its guide during operation. This can cause oil consumption (oil leaks past the valve seal and through the guide), burned valves (poor seat to valve face seal), or valve breakage.

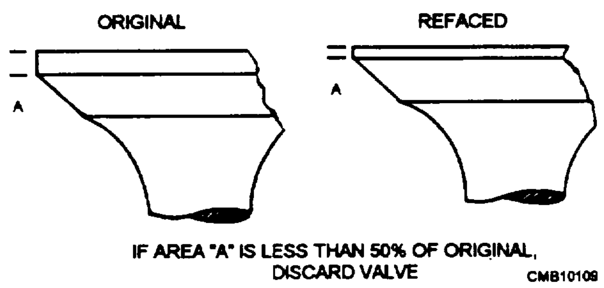


Figure 3-58.—Proper valve margin of thickness after refacing.

There are several satisfactory methods of checking for valve guide wear. One procedure for checking valve guide wear is to slide the valve into its guide. Full it open approximately 1/2 inch, then try and wiggle the valve sideways. If the valve moves sideways in any direction, the guide or stem is worn Another checking procedure involves the use of a small hole gauge to measure the inside of the guide and a micrometer to measure the valve stem; the difference in the readings is the clearance. Check the manufacturer's manual for the maximum allowable clearance. When the maximum clearance is exceeded the valve guide needs further servicing before you proceed with the rest of the job.

Servicing procedures depend on whether the guide is of the integral or replaceable type. If it is the integral type, it must be reamed to a larger size and a valve with an oversize stem installed. But if it is replaceable, it should be removed and a new guide installed

KNURLING of the valve guides has become more popular as a method of compensating for wear of the valve guides. Knurling is accomplished by attaching a special tool to an electric drill and inserting the tool in the worn guide. This method is not recommended if the guide has been worn excessively or knurled previously.

Valve guides should be removed and replaced with special drivers (fig. 3-59). When working on a valve in the cylinder head of an engine, you may use an arbor press to remove and replace the valve guides.

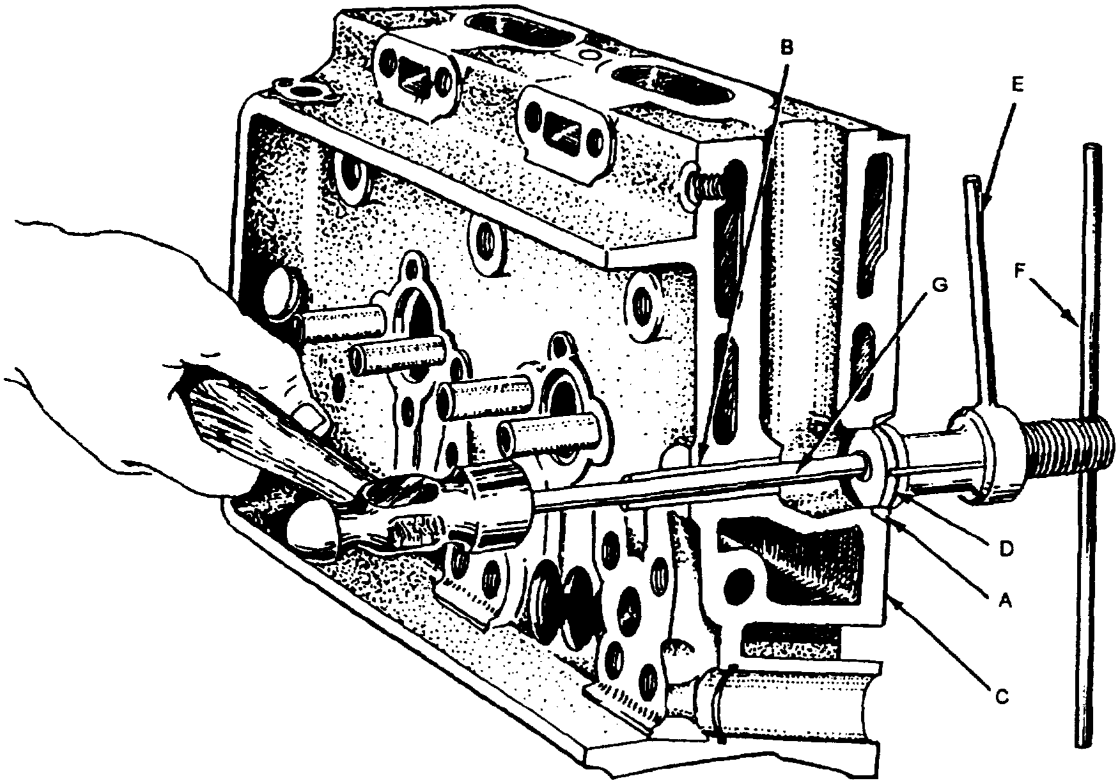
After the valve guides are serviced and the valve seats are ground, check the concentricity of the two with a valve seat dial indicator (fig. 3-60). Any irregularity in the seat will register on this dial.

Valve Seat Service

Valve seat service requires either replacement of the seat or reconditioning of the seat by grinding or cutting. Valve seat replacement is required when a valve seat is cracked, burned, or recessed (sunk) in the cylinder head Normally, valve seats can be machined and returned to service.

To remove a replaceable pressed-in seat, split the old seat with a sharp chisel. Then pry out the old seat. New seat inserts should be chilled in dry ice for about 15 minutes to shrink them, so they can be driven into place easily. The seat expands when returned to room temperature, which locks the seat in place.

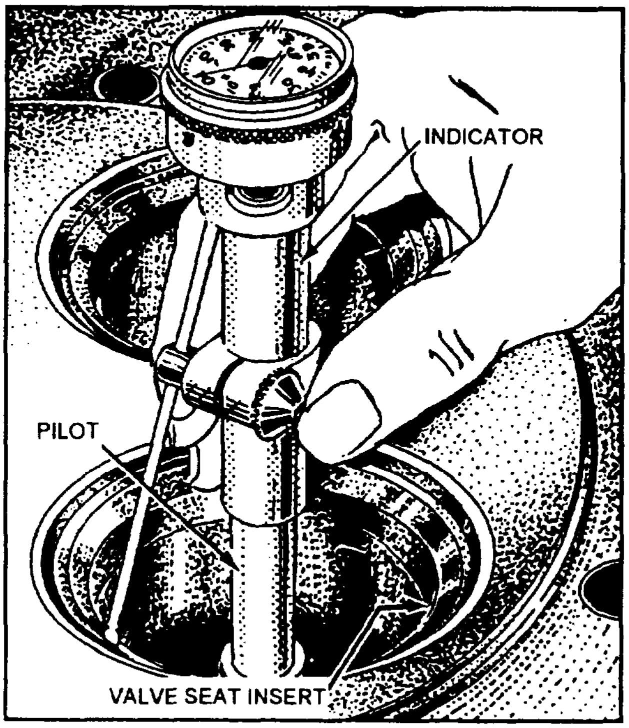
In most cases, the valve seats are not replaceable, so they must be ground (fig. 3-61). Before operating the valve seat grinding equipment in your shop, be sure to study the manufacturer's manual for specific



A. INSERT, VALVE SEAT
B. GUIDE, EXHAUST VALVE
C. CYLINDER HEAD
D. COLLET
E. HANDLE, COLLET
F. T HANDLE
G. BAR, DRIVE

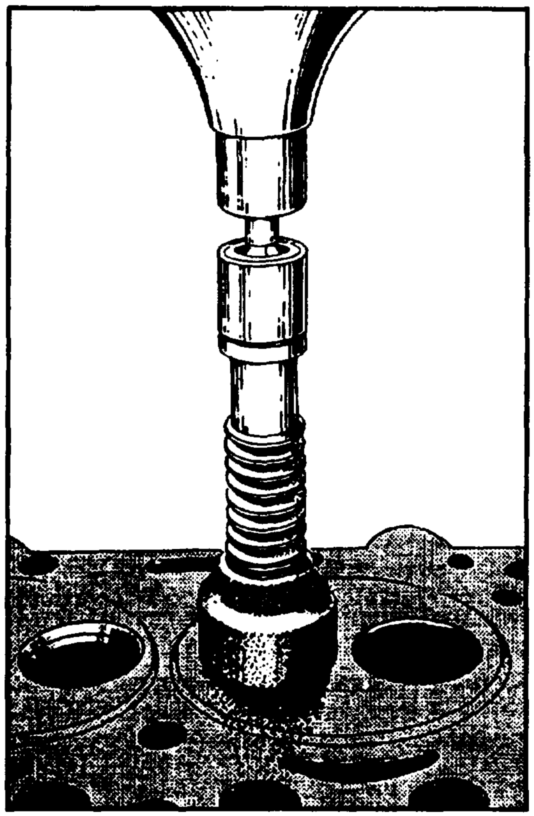
CMB10110

Figure 3-59.—Puller used in removing valve seat inserts.



CMB10111

Figure 3-60.—Determining concentricity of the valve seat with a valve seat dial indicator.



CMB10112

Figure 3-61.—Grinding valve seats using a concentric type of grinder.

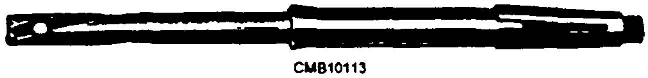


Figure 3-62.—Self-centering pilot.

instructions. The following procedures are typical for grinding valve seats:

- Select and install the correct size pilot (metal shaft that fits into the guide and supports cutting stone or carbide cutter) (fig. 3-62). The pilot should fit snugly in the valve guide and not wiggle.
- Select the correct stone for the valve seat. It must be slightly larger in diameter than the seat and must have the correct face angle. Slip the stone-and-sleeve assembly over the pilot.
- Insert the power head into the sleeve assembly. Support the weight of the power head. Grind only long enough to clean up pits in the seat. Check the progress often to ensure that you do not remove more material than necessary to get a good seat.

After grinding valve seats, it is recommended that you lap the contact surfaces of the valve and valve seat. Lapping valves are done to check the location of the valve-to-seat contact point and to smooth the mating surfaces.

To lap the valve, dab grinding compound (abrasive paste) on the valve face. Install the valve into the cylinder head and rotate with a lapping stick (a wooden stick with a rubber plunger for holding the valve head). Rub your hands back and forth on the lapping stick to spin the valve on its seat. This rubs the grinding compound between the valve face and the seat. Remove the valve and check the contact point. A dull gray stripe around the seat and face of the valve indicates the valve-to-seat contact point. This helps you narrow or move the valve seat. A few manufacturers do **NOT** recommend valve lapping. Refer to the manufacturer's service manual for details.

WARNING

Make sure you clean all of the valve grinding compound off the valve and cylinder head. The compound can cause rapid part wear.

Another way to check valve-to-seat contact is by spreading a thin coat of prussian blue on the valve face or putting lead pencil marks on the valve seat. If, when turning the valve on its seat, an even deposit of coloring is seen on the valve seat or the pencil lines are removed, the seating is perfect. The valve should **NOT** be rotated more than one-eighth turn as a high spot could give a false indication if turned one full revolution.

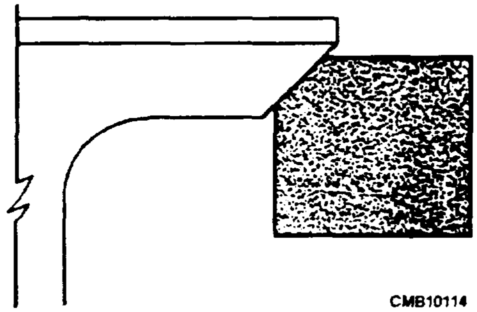


Figure 3-63.—Normal valve seat.

Figure 3-63 shows a normal valve seat. This will vary according to the manufacturer's specification. The seat should touch near the center of the valve face with the correct contact width. Typically, an intake valve should have a valve-to-seat contact width of about 1/16 of an inch. An exhaust valve should have a valve-to-seat contact width of approximately 3/32 of an inch. Check the manufacturer's service manual for exact values.

When the valve seat does **NOT** touch the valve face properly (wrong width or location on the valve) (fig. 3-64), regrind the seat using different angles, usually 15-degree and 60-degree stones. This is known as narrowing or positioning a valve (fig. 3-65).

To move the seat in and narrow it, grind the valve seat with a 15-degree stone. This removes metal from around the top of the seat. The seat face moves closer to the valve stem.

To move the seat out and narrow it, grind the valve seat with a 60-degree stone. This cuts away metal from the inner edge of the seat. The seat contact point moves toward the margin *or* outer edge of the valve.

Rocker Arm Service

After disassembling the rocker arms, you should inspect them for wear, clogged oil holes, and damage.

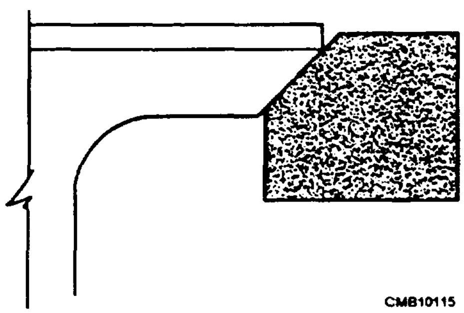


Figure 3-64.—Incorrect valve-to-seat contact.

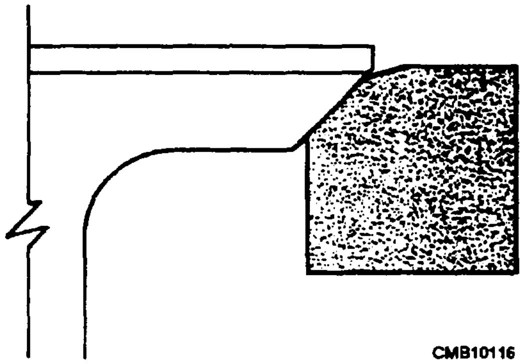


Figure 3-65.—Correct valve-to-seat contact after narrowing.

When wear is indicated inside the rocker bore, you can measure it with a telescoping gauge and a micrometer or a bore gauge. Rocker arms with bushings can be rebushed if the old bushing is worn On some rocker arms, worn valve ends can be ground down on the valve grinding machine. Excessively worn rocker arms should be replaced.

Also, inspect the rocker arm shaft for wear. A worn rocker arm shaft has indentions where the rocker arms swivel on the shaft. Wear on the shaft is usually greater on the bottom. Using a micrometer, check the shaft to determine whether wear is within the manufacturer's specifications.

When reinstalling rocker arms and shafts in the cylinder head, make sure that the oil holes (in the shaft if so equipped) are on the underside, so they can feed oil to the rocker arms. Ensure that all spring and rocker arms are restored to their original positions as you attach the shafts to the head.

Valve Spring Service

After prolonged use, valve springs tend to weaken, lose tension, or even break. During engine service, always test valve springs to make sure they are usable. Valve springs should be tested for uniformity and strength. The three characteristics to check are valve spring squareness, valve spring free height, and valve spring tension.

Valve spring squareness is easily checked with a combination square. Place each spring next to the square on a flat surface. Rotate the spring while checking for a gap between the side of the spring and the square. Replace any spring that is not square.

Valve spring free height can also be measured with a combination square or a valve spring tester. Simply measure the length of each spring in normal uncompressed condition. If it is too long or too short, replace the spring.

Valve spring tension, or pressure, is measured by using a spring tester. Compress the spring to specification height and read the scale on the tester. Spring pressure must be within specifications. If the reading is too low, the spring has weakened and must be replaced.

TIMING GEARS (GEAR TRAINS)

Because the crankshaft must rotate twice as fast as the camshaft, the drive member on the crankshaft must be exactly one half as large as the driven member on the camshaft So for the camshaft and crankshaft to work together, they must be in time with each other. This initial position between the two shafts is designated by marks that are called **timing marks.** To obtain the correct initial relationship of the components, align the corresponding marks at the time of assembly. Timing gears keep the crankshaft and the camshaft turning in proper relation to one another, so the valves open and close at the proper time. This is accomplished by gear-drive, chain-drive, or belt-drive gear trains (fig. 3-66).

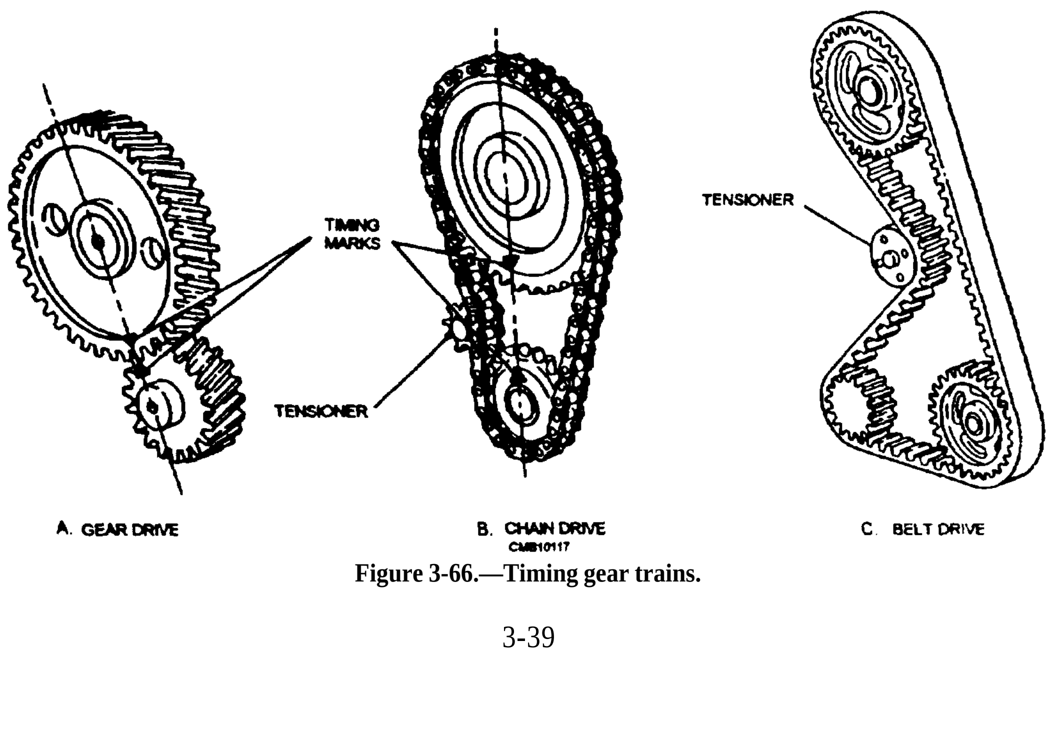


Figure 3-66.—Timing gear trains.

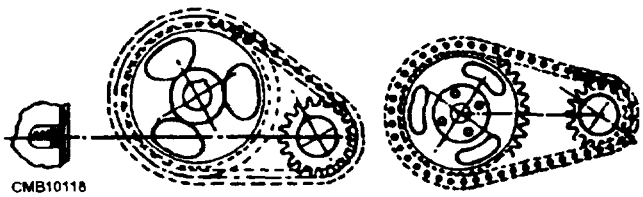


Figure 3-67.—Methods of valve timing with a chain drive.

In a gear drive setup (fig. 3-66), the timing gear on the crankshaft meshes directly with the gear on the camshaft. Timing gears are commonly used on heavy-duty applications due to their dependability; however, they are noisier than a chain or belt drive. Since they are keyed to their respective shafts, they can be replaced if they become worn. With directly driven gears, one gear usually has a mark on two adjacent teeth and the other mark on only one tooth. To time the valve properly, mesh the gears so the two marked teeth of one gear straddle the single marked tooth of the other.

A timing chain and sprockets can also be used to turn the camshaft (fig. 3-66). This is the most common type of gear train. There are two types of timing chains. One is a silent link type that is used in standard and light-duty applications. The other is the roller-link chain, which is used in heavy-duty applications. Like timing gears, the chain sprockets have timing marks. The correct timing may be obtained by hating a certain number of chain-link teeth between the marks or by lining up the marks with a straightedge, as shown in figure 3-67.

In a belt drive gear train, the sprockets on the crankshaft and the camshaft are linked by a continuous neoprene belt (fig. 3-66). The belt has square-shaped internal teeth that mesh with the teeth on the sprockets. The timing belt is reinforced with nylon or fiber glass to give it strength and prevent it from stretching. This drive configuration is limited to overhead camshaft engines.

Most engines with a chain drive and all belt-driven engines use a tensioner. The tensioner pushes against the belt or chain to keep it tight. This serves to keep it from slipping on the sprockets. This provides more precise valve timing and compensates for component wear and stretch. Engines with a belt drive usually use a spring-loaded idler wheel. Engines with a chain drive use a fiber-rubbing block that is either spring loaded or hydraulic.

NOTE

Always check the manufacturer's service manual when you are in doubt about the method of timing used for the engine you are overhauling.

ENGINE BEARINGS

Bearings are installed in an engine where there is relative motion between parts. Engine bearings are called sleeve bearings because they are in the shape of a

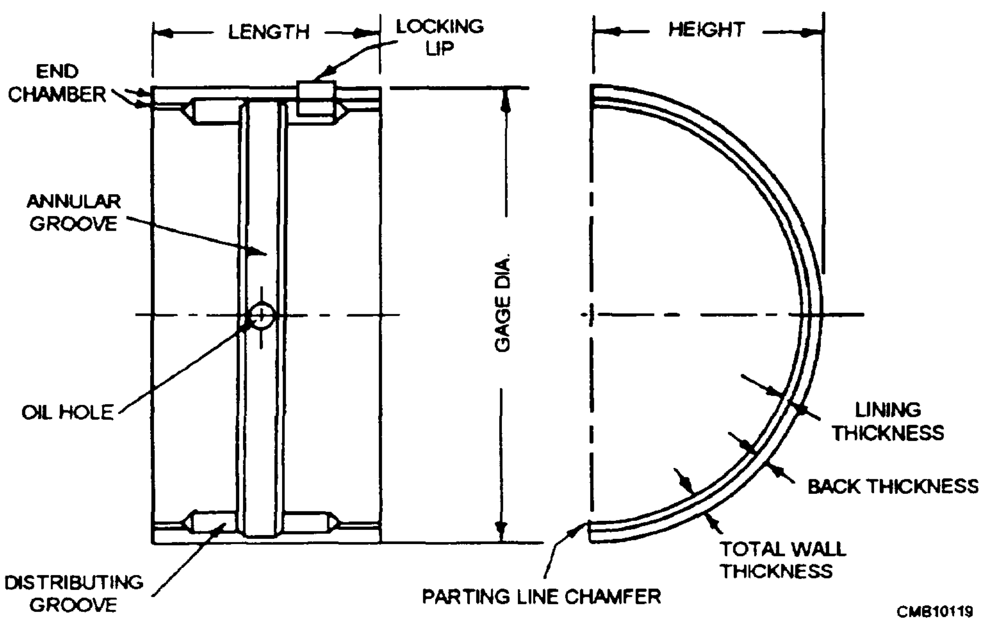


Figure 3-68.—Typical sleeve-type bearing half.

sleeve that fits around the rotating journal or shaft (fig. 3-68). Connecting rod or camshaft (main) bearings are of the split or half type (fig. 3-69). On main bearings, the upper half is installed in the counterbore in the cylinder block. The lower-bearing half is held in place by the bearing cap (fig. 3-70). On connecting rod bearings, the upper-bearing half is installed in the rod and the lower half is placed in the rod cap. The piston pin bearing in the connecting rod is of the full round or bushing type.

Bearing Lubrication

The lubrication of bearings is very important to engine service life because it forces oil to high friction points within the engine. Without lubrication between parts, bearings overheat and score from friction.

The journal or shaft must be smaller in diameter than the bearing (fig. 3-71), so there is clearance (called oil clearance) between the two parts; oil circulates through the clearance. The oil enters through the oil hole (fig. 3-66) and fills the oil groove in the bearing. From there, the rotating journal carries the oil around to all moving parts of the bearing. The oil works its way to the outer edges of the bearing. From there, it is thrown off and drops back into the oil pan. The oil thrown off helps to lubricate other engine parts, such as the cylinder walls, the pistons, and the piston rings.

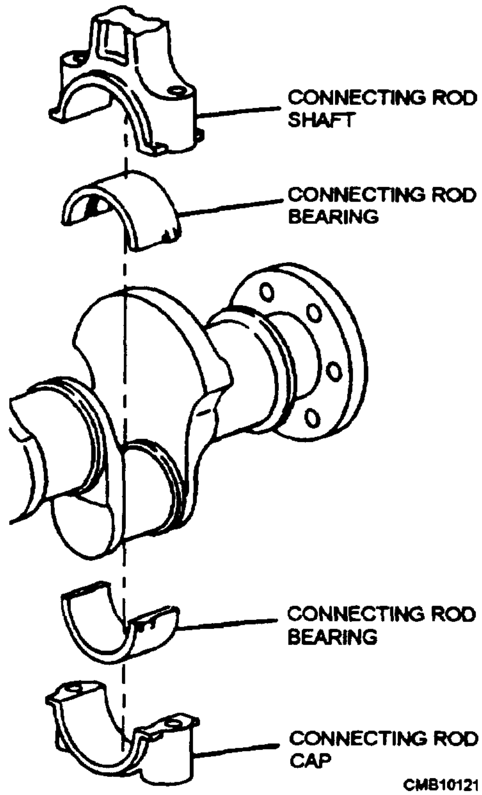


Figure 3-70.—Connecting rod bearings.

As the oil moves across the faces of the bearings, it not only lubricates them but also helps keep them cool. The oil is relatively cool, as it leaves the oil pan. It picks up heat in its passage through the bearing. This heat is

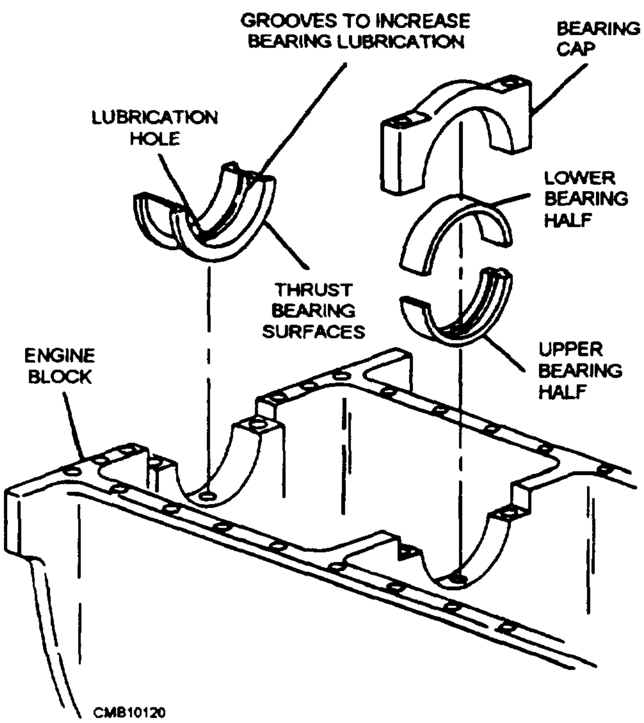


Figure 3-69.—Crankshaft main bearings.

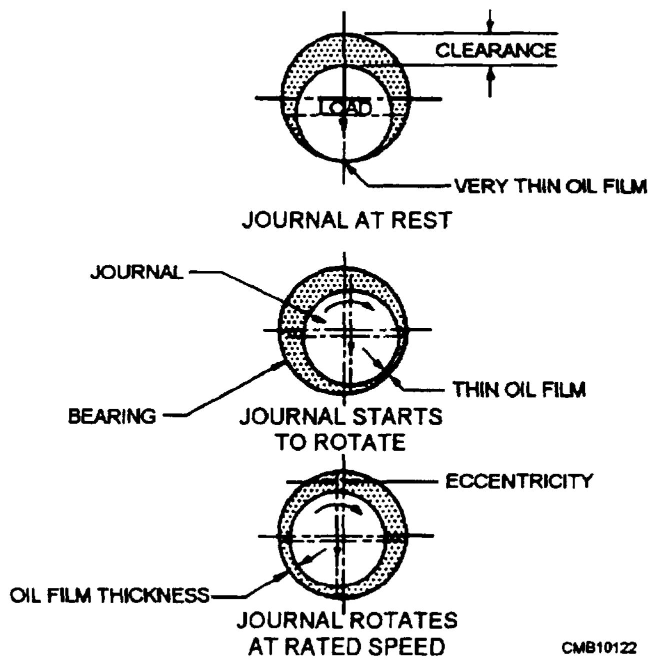


Figure 3-71.—Oil clearance between bearing and shaft.

carried down to the oil pan and released to the air passing around the oil pan. The oil also flushes and cleans the bearings. It tends to flush out particles of grit and dirt that may have worked into the bearing. The particles are carried back to the oil pan by the circulating oil. The particles then drop to the bottom of the oil pan or are removed from the oil by the oil screen or filter.

The greater the oil clearance, the faster the oil flows through the bearing; however, excessive oil clearance causes some bearings to fail from oil starvation. Here's the reason: If oil clearances are excessive, most of the oil passes through the nearest bearings. There is not enough oil for the most distant bearings; these bearings eventually fail from lack of oil. An engine with excessive bearing oil clearance usually has low oil pressure; the oil pump cannot build up normal pressure because of the excessive oil clearance in the bearings.

On the other hand, when the bearings have insufficient oil clearances, there is metal-to-metal contact between the bearings and the journal. Extremely rapid wear and quick failure is the end result. Also, there is not enough throw off for adequate lubrication of cylinder walls, pistons, and rings.

Bearing Characteristics

Engine bearings must operate under tremendous loads, severe temperature variations, abrasive action, and corrosive surroundings. Essential bearing characteristics include the following.

BEARING LOAD STRENGTH is the ability of a bearing to withstand pounding and crushing during engine operations. The piston and rod can produce several TONS of downward force. The bearing must not fatigue, flatten, or split under these loads. If the bearing load resistance is too low, the beating can smash, fail, and spin in its bore. This ruins the bore or the journal.

BEARING CONFORMABILITY is the ability of a bearing to move, shift, conform to variations in shaft alignment, and adjust to imperfections in the surface of the journal. Usually, a soft metal is placed over hard steel. This lets the bearing conform to the defects in the journal.

BEARING EMBEDABILITY refers to the ability of a bearing to permit foreign particles to become embedded in it (fig. 3-72). Dirt and metal are sometimes carried into the bearings. The bearing should allow the particles to sink beneath the surface into the bearing material. This prevents the particles from scratching, wearing, and damaging the surface of the crankshaft or camshaft journals.

BEARING CORROSION RESISTANCE is the ability of a bearing to resist corrosion from acid, water, and other impurities in the engine oil. Combustion blow-by gases cause engine oil contamination that can also corrode engine bearings. Aluminum-lead and other alloys are commonly being used because of their excellent corrosion resistance.

Bearing Materials

As discussed earlier, there are three basic types of engine bearings—connecting rod bearings, crankshaft main bearings, and camshaft bearings. The backing material (body of the bearing that contacts stationary parts) for engine bearings is normally steel. Softer alloys are bonded over the backing to form the bearing surface. Any one of three basic types of metal alloys can be plated over the top of the steel backing—Babbitt (lead-tin alloy), copper, or aluminum (fig. 3-73). These three metals may be used in different combinations to design bearings for either light-, medium-, or heavy-duty applications. The engine designer selects the combination of ingredients that will best suit the engine.

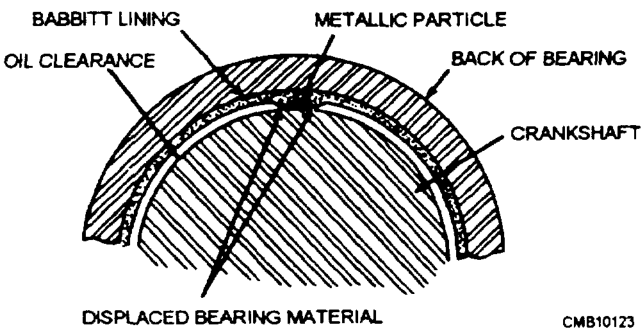


Figure 3-72.—Effect of a metallic particle embedded in bearing material (Babbitt lining).

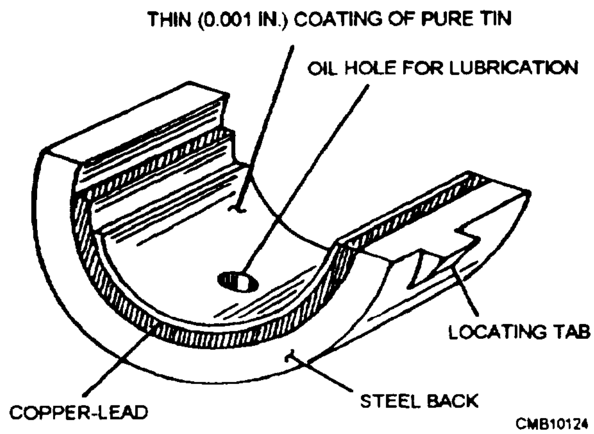


Figure 3-73.—Bearing materials

Q1. What material is commonly used to provide a wearing surface in a liquid-cooled engine for the pistons to ride against?

Q2. What are the two types of cylinder sleeves?

Q3. What are the two types of core hole plugs used in an internal combustion engine?

Q4. What is the basic foundation of all air-cooled engines ?

Q5. A properly made exhaust manifold results in what type of action to help an engine get rid of exhaust gases?

Q6. In an exhaust-heated intake manifold, gases diverted to the manifold are controlled by what valve?

Q7. What two basic types of oil seals are currently being used on engines?

Q8. What ate the structural components of a piston?

Q9. What are the three types of piston pin configurations?

Q1O. What three functions do piston rings serve?

Q11. What part is the backbone of an internal combustion engine?

Q12. The valve actuating mechanism is made up of what engine parts?

Q13. What are the three basic shapes of a poppet-type valve ?

Q14. What type of valve is preferred in a vehicle using unleaded fuel?

Q15. What are the two basic types of valve seals?

Q16. What three characteristics of a valve spring should you check?

ENGINE ADJUSTMENT AND TESTING

LEARNING OBJECTIVE: *Describe The techniques used in adjusting engine valves. Recognize basic engine testing procedures and required tools.*

Proper and uniform valve adjustments are required for a smooth running engine. Unless the clearance between the valve stems and rocker arms or valve lifters is adjusted according to the manufacturer's specifications, a valve does not open and close at the proper time, and engine performance is affected.

In most shops, the Navy provides accurate and dependable testing equipment. But having the testing equipment in the shop is **NOT** enough. The supervisor and crew must know how to use this equipment properly since it provides the quickest and surest means of determining what is wrong and where the fault lies.

VALVE ADJUSTMENT

Valve adjustment, also called tappet clearance adjustment or rocker adjustment, is critical to the performance and service life of an engine. If the valve train is too loose (too much clearance), it can cause valve train noise (tapping or clattering noise from the rocker striking the valve stems). This can increase part wear and cause part breakage. Valves that are adjusted too tight (inadequate clearance) may be held open or may not close completely. This can allow combustion heat to blow over and burn the valve.

When reassembling an engine after reconditioning the valves, make sure the adjusting screws are backed off before rotating the engine. A valve that is too tight could strike the piston and damage either the piston or the valve, or both. Adjust the valve according to manufacturer's specifications, following the recommended procedure.

On any engine, after valve adjustments have been made, be sure that the adjustment locks are tight and that the valve mechanism covers and gaskets are in place and fastened securely to prevent oil leaks.

Overhead Valves

Most overhead valves are adjusted **"HOT";** that is, valve clearance recommendations are given for an engine at operating temperature. Before valve adjustments can be made properly, the engine must be run and brought up to normal operating temperature.

To adjust a valve, remove the valve cover and measure the clearance between the valve stem and the rocker arm. Loosen the locknut and turn the adjusting screw in the rocker arm, as shown in figure 3-74. On engines with stud-mounted rocker arms, make the adjustment by turning the stud nut.

Valves in Block

This type of valve arrangement is not commonly seen in the field; however, the adjustment procedure is described in case you should happen to run across this type.

Valves within the block are adjusted **"COLD";** that is, recommended valve clearances are provided for a cold engine. These valves have mechanisms quite similar to overhead valves. They are adjusted by removing the side cover plate beneath the intake manifold on the side of the engine block (fig. 3-75). Since you must stop the engine to adjust the valves, the piston in the cylinder must be on TDC of the compression stroke. You can determine this by watching the valves of the piston that is paired with the one that is being set. As the cylinder that is being positioned is coming up on the compression stroke, the paired cylinder is coming up on the exhaust stroke; therefore, the exhaust valve is open. Just as the exhaust valve closed and the intake valve begins to open, the cylinder to be set is on TDC of the compression stroke, and you can set the two valves. Once the No. 1 cylinder is positioned, follow through according to the firing order of the engine, as this makes the job easier and faster. You may also use this procedure when adjusting valves on overhead engines.

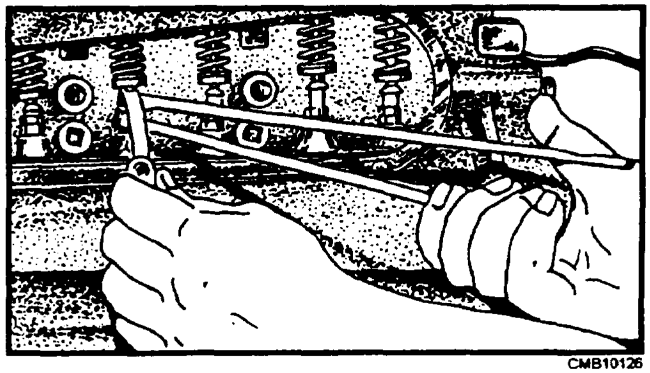


Figure 3-75.—Adjusting valve in block.

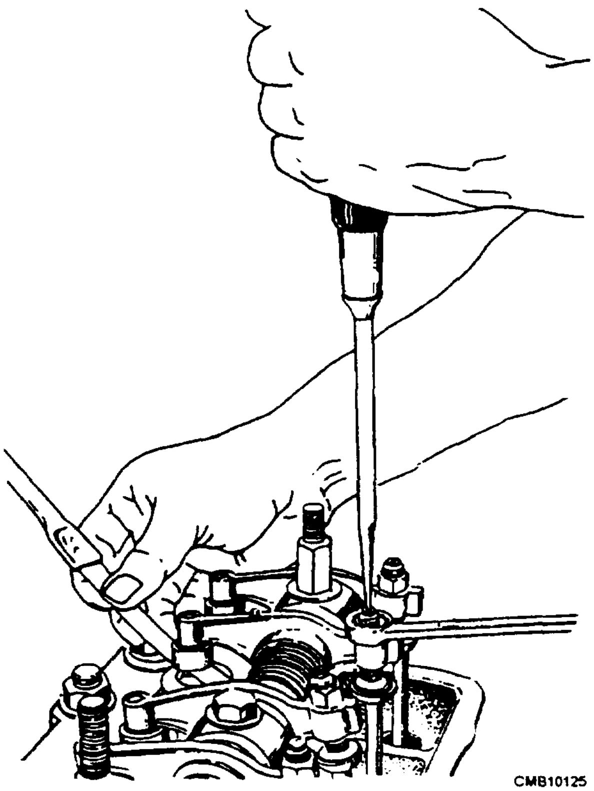


Figure 3-74.—Adjusting overhead valves.

Hydraulically Operated Valves

On engines with hydraulic valve lifters, it is not necessary to adjust the valve periodically. The engine lubrication system supplies a flow of oil to the lifters at all times. These hydraulic lifters operate at zero clearance and compensate for changes in engine temperature, adapt automatically for minor wear at various points, and provide ideal valve timing.

To adjust hydraulic lifters with the engine off, turn the crankshaft until the lifter is on the camshaft base circle (not the lobe). The valve must be fully closed. Loosen the adjusting nut until you can wiggle the pushrod up and down. Then slowly tighten the rocker until all play is out of the valve train (cannot wiggle pushrod). Repeat the adjusting procedure on the other rockers.

To adjust hydraulic lifters with the engine running, install a special oil shroud or some other device for catching oil spray off the rocker. Start and run the engine until it reaches operating temperature. Tighten all rockers until they are quiet. One at a time, loosen a rocker until it clatters. Then tighten the rocker slowly until it quiets down. This is zero valve lash.

OHC Engine Valves

There are several different methods of adjusting the valves on an overhead cam (OHC) engine. Many are adjusted like mechanical lifters in a pushrod engine. The rocker arm adjuster is turned until the correct size feeler gauge fits between the rocker or cam lobe and the valve stem.

Valve adjusting shims may also be used on OHC engines for the cam-to-valve clearance. To determine whether shims are required, measure the valve clearance with a feeler gauge. Then, if needed remove or change the shim thickness as necessary.

Other OHC engines have an Allen adjusting screw in the cam followers. Turning the screw changes the valve clearance. Always refer to the manufacturer's manual for detailed instructions.

COMPRESSION TEST

A compression test is one of the most common methods for determining the mechanical condition of an engine. It should be done when symptoms (engine miss, rough idle, puffing noise in induction or exhaust) point to major engine problems. Measure compression pressures of all cylinders with a compression gauge (fig. 3-76). Then compare them with each other and with the manufacturer's specifications for a new engine. This provides an accurate indication of engine condition.

When gauge pressure is lower than normal, pressure is leaking out of the combustion chamber. Low engine compression can be caused by the following conditions:

- **BURNED VALVE** (valve face damaged by combustion heat).
- **BURNED VALVED SEAT** (cylinder head seat damaged by combustion).
- **PHYSICAL ENGINE DAMAGE** (hole in piston, broken valve, etc.).
- **BLOWN HEAD GASKET** (head gasket ruptured).

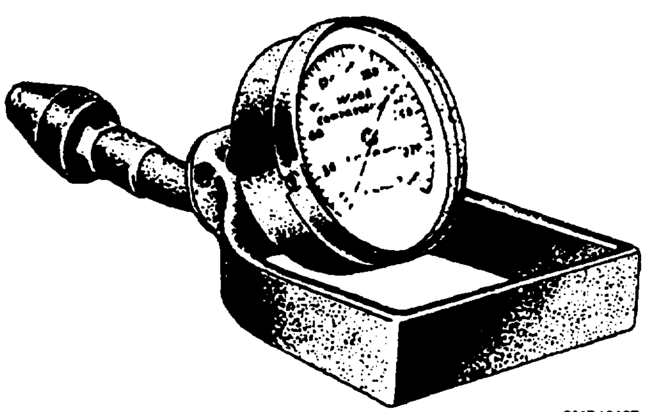


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Figure 3-76.—Cylinder compression tester.

- **WORN RINGS OR CYLINDERS** (part wear that prevents a ring-to-cylinder seal).
- **VALVE TRAIN TROUBLES** (valve adjusted with insufficient clearance. This keeps the valve from fully closing. Also, broken valve spring, seal, or retainer).
- **JUMPED TIMING CHAIN OR BELT** (loose or worn chain or belt has jumped over teeth, upsetting valve timing).

To perform a compression test on a gasoline engine, use the following procedures:

- Remove all spark plugs so the engine can rotate easily. Block open the carburetor or fuel injection pump throttle plate. This prevents restricted air flow into the engine.
- Disable the ignition system to prevent sparks from arcing out of the disconnected spark plug wires. Usually, the feed wire going to the ignition coil can be removed to disable the system.
- If the engine is equipped with electronic fuel injection, it should also be disabled to prevent fuel from spraying into the engine. Check the manufacturer's manual for specific directions.
- Screw the compression gauge into one of the spark plug holes. Some gauges have a tapered rubber-end plug and must be held by hand securely in the spark plug opening until the highest reading is obtained.
- Crank the engine and let the engine rotate for about four to six compression strokes (compression gauge needle moves four to six times). Write down the gauge readings for each cylinder and compare them to the manufacturer's specifications.

The compression test for a diesel engine is similar to that of a gasoline engine; however, do not use the compression gauge intended for a gasoline engine. It can be damaged by the high-compression-stroke pressure. A diesel gauge must be used that reads up to approximately 600 psi.

To perform a diesel compression test, use the following procedures:

- Remove all injectors or glow plugs. Refer to the manufacturer's manual for instructions.

- Install the compression gauge in the recommended opening. A heat shield must be used to seal the gauge when it is installed in place of the injector.
- Disconnect the fuel shut-off solenoid to disable the fuel injection pump.
- Crank the engine and note the highest reading on the gauge.

A wet compression test should be used when cylinder pressure reads below the manufacturer's specifications. It helps you to determine what engine parts are causing the problem. Pour approximately 1 tablespoon of 30-weight motor oil into the cylinder through the spark plug or injector opening, then retest the compression pressure.

If the compression reading *GOES UP* with oil in the cylinder, the piston rings and cylinders may be worn and leaking pressure. The oil will temporarily coat and seal bad compression rings to increase pressure; however, if the compression reading *STAYS ABOUT THE SAME,* then engine valves or head gaskets may be leaking. The engine oil seals the rings, but does **NOT** seal a burned valve or a blown head gasket. In this way, a wet compression test helps diagnose low-compression problems.

Do **NOT** put too much oil into the cylinder during a wet compression test or a false reading may result. With excessive oil in the cylinder, compression readings go up even if the compression rings and cylinders are in good condition.

NOTE

Some manufacturers warn against performing a wet compression test on diesel engines. If too much oil is squirted into the cylinder, hydraulic lock and part damage may result, because oil does **NOT** compress in the small cylinder volume.

Compression readings for a gasoline engine should run around 125 to 175 psi. The compression should not vary over 15 to 20 psi from the highest to the lowest cylinder. Readings must be within 10 to 15 percent of each other. Diesel engine compression readings average approximately 275 to 400 psi, depending on the design and compression ratio. Compression levels must not vary more than about 10 to 15 percent (30 to 50 psi). Look for cylinder variation during an engine compression check. If some cylinders have normal pressure readings and one or two have low readings, engine performance is reduced. If two adjacent cylinders read low, it might point to a blown head gasket between the two cylinders. If the compression pressure of a cylinder is low for the first few piston strokes and then increases to near normal, a sticking valve is indicated. Indications of valve troubles by compression test may be confirmed by taking vacuum gauge readings.

VACUUM GAUGE TEST

When an engine has an abnormal compression reading, it is likely that the cylinder head must be removed to repair the trouble. Nevertheless, the mechanics should test the vacuum of the engine with a gauge. The vacuum gauge provides a means of testing intake manifold vacuum, cranking vacuum, fuel pump vacuum, and booster pump vacuum. The vacuum gauge does **NOT** replace other test equipment, but rather supplements it and diagnoses engine trouble more conclusively.

Vacuum gauge readings are taken with the engine running and must be accurate to be of any value; therefore, the connection between the gauge and the intake manifold must be leakproof. Also, before the connection is made, see that the openings to the gauge and the intake manifold are free of dirt or other restrictions.

When a test is made at an elevation of 1,000 feet or less, an engine in good condition, idling at a speed of about 550 rpm, should give a steady reading from 17 to 22 inches on the vacuum gauge. The average reading will drop approximately 1 inch of vacuum per 1,000 feet at altitudes of 1,000 feet or higher above sea level.

When the throttle is opened and closed suddenly, the vacuum reading should first drop about 2 inches with the throttle open, and then come back to a high of about 24 inches before settling back to a steady reading as the engine idles, as shown in figure 3-77. This is normal for an engine in good operating condition.

If the gauge reading drops to about 15 inches and remains there, it would indicate compression leaks between the cylinder walls and the piston rings or power loss caused by incorrect ignition timing. A vacuum gauge pointer indicating a steady 10 inches, for example, usually means that valve timing of the engine is incorrect. Below-normal readings that change slowly between two limits, such as 14 and 16 inches, could indicate a number of problems. Among them are improper carburetor idling adjustment, maladjusted or

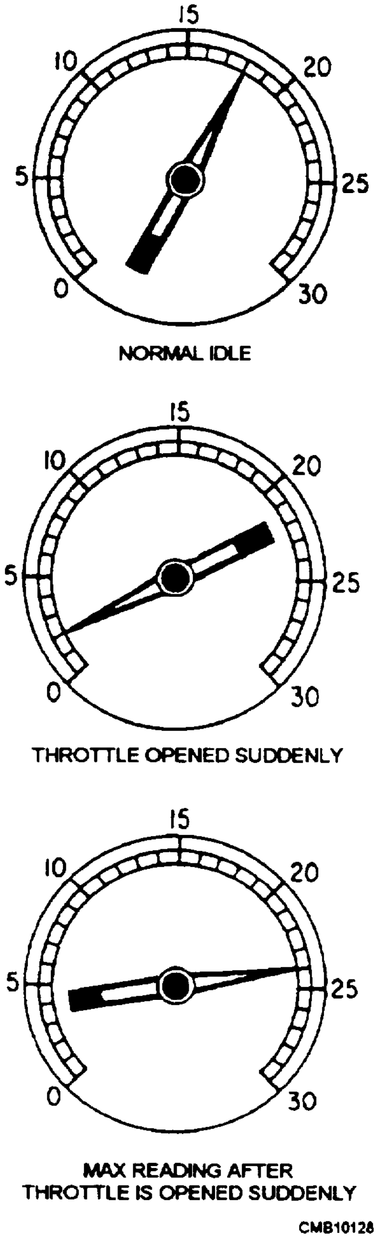

Figure 3-77.—Approximate vacuum gauge readings on a normal operating engine.

burned breaker points, and spark plugs with the electrodes set too closely.

A sticking valve could cause the gauge pointer to bounce from a normal steady reading to a lower reading and then bounce back to normal. A broken or weak valve spring can cause the pointer to swing widely, as the engine is accelerated. A loose intake manifold or leaking gasket between the carburetor and manifold shows a steady low reading on the vacuum gauge.

A vacuum gauge test only helps to locate the trouble. It is not conclusive, but as you gain experience in interpreting the readings, you can usually diagnose engine behavior.

CYLINDER LEAKAGE TEST

Another aid in locating compression leaks is the cylinder leakage tester. The principle involved is that of simulating the compression that develops in the cylinder during operation. Compressed air is introduced into the cylinder through the spark plug or injector hole, and by listening and observing at certain key points, you can make some basic deductions.

The commercial testers, such as the one shown in figure 3-78, have a gauge indicating a percentage of air loss. The gauge is connected to a spring-loaded diaphragm. The source of air is connected to the instrument and counterbalances the action of the spring against the diaphragm. By adjusting the spring tension, you can calibrate the gauge properly against a variety of air pressure sources within a given tolerance.

In making a cylinder leakage test, remove all spark plugs, so each piston can be positioned without the resistance of compression of the remaining cylinders. Next, place the piston at TDC or "rock" position between the compression and power strokes. Then you can introduce the compressed air into the cylinder. Note that the engine tends to spin. Now, by listening at the carburetor, the exhaust pipe, and the oil filler pipe (crankcase), and by observing the coolant in the radiator, when applicable, you can pinpoint the area of

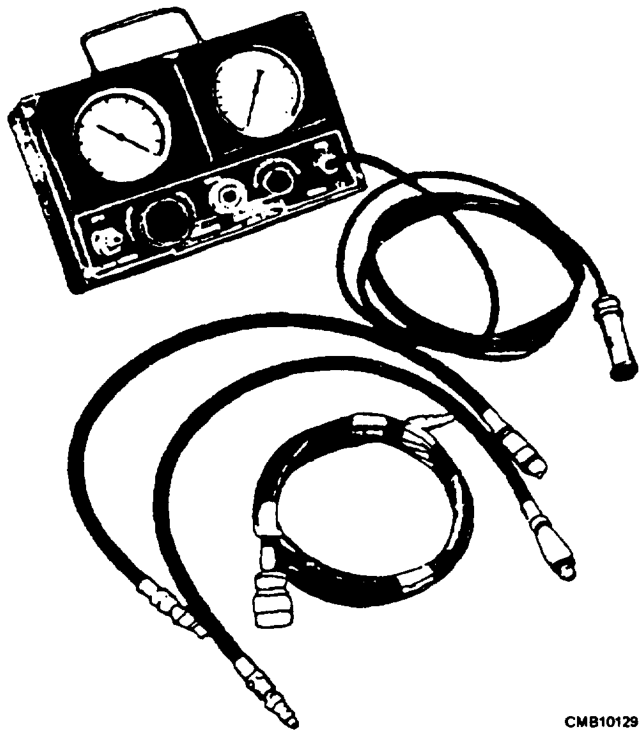

Figure 3-78.—Cylinder leakage tester.

air loss. Aloud hissing of air at the carburetor indicates a leaking intake valve, or valves. Excessive hissing of air at the oil filler tube (crankcase) indicates an excessive air leak past the piston rings. Bubbles observed in the coolant at the radiator indicates a leaking head gasket

As in vacuum testing, indications are not conclusive. For instance, a leaking head gasket may prove to be a cracked head, or bad rings may be a scored cylinder wall. The important thing is that the source of the trouble has been pinpointed to a specific area, and a fairly broad, accurate estimate of repairs or adjustments required can be made without dismantling the engine.

Q17. Overhead valves are adjusted with the engine in what condition ?

Q18. When you perform a wet compression test and the reading goes up, what is the most likely problem?

Q19. You make a vacuum gauge test at sea level with the engine idling at 550 rpm, and you get a reading of 10 inches. What is the most probable cause?

Q20. When performing a cylinder leakage test, you notice a loud hissing of air from the carburetor. This is an indication of what type of problem?